WATER POWER

A technical journal devoted to the study of all aspects of Hydro-electric developments

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Owen Falls Many miles of power, distribution and control cables for the first section of this great scheme were supplied and installed for the Uganda Electricity Board by the BICC Group, who are also erecting 120 miles of 132kV overhead line to carry power to Tororo and Kampala.

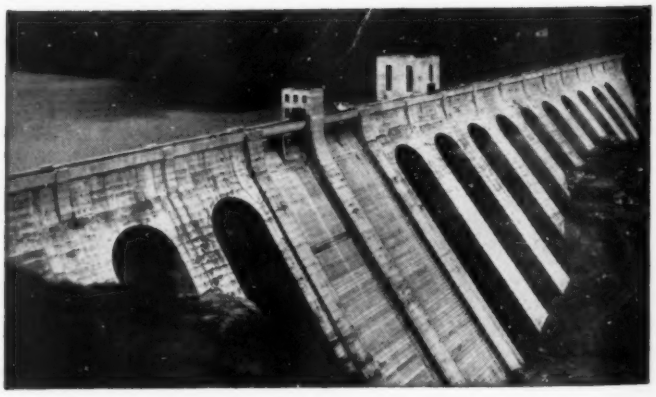
Consulting Engineers:
Sir Alexander Gibb & Partners and Messrs. Kennedy & Donkin.

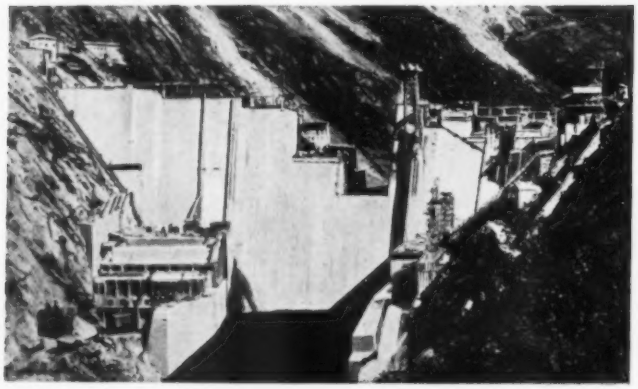
3 Major Hydro-Electric Schemes

USING BICC TRANSMISSION EQUIPMENT

No two hydro-electric schemes are identical. Each presents a new set of problems to the transmission engineer, for terrain, climate and location are all important factors in the design, supply and installation of transmission equipment.

That is why BICC are so often employed on work of this nature. With their wide overseas representation, they have first hand knowledge of the difficulties likely to be encountered. Long experience and vast manufacturing resources enable them to supply and install hydro-electric transmission equipment anywhere in the World.





Loch Sloy This scheme is now connected with the Clachan power station of the Glen Shira Hydro-Electric Scheme by a nine mile single circuit 132kV overhead line. It was erected for the North of Scotland Hydro-Electric Board by the BICC Group. *Consulting Engineers:* Messrs. Merz & McLellan of London.

Los Peares At Los Peares, Spain, Fuerzas Electricas del Noroeste S.A. (Fenosa) have erected a dam and a 160,000kW power station. 2,000 ft. of BICC Mass-Impregnated Non-Draining multi-core control cables connect the power station with the switch station. They were supplied through our agents in Madrid, Dugopa S.L., to the British Thomson-Houston Co., Ltd.—main contractors.

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WATER POWER

A technical journal devoted to the study of all aspects of Hydro-Electric Development

Civil Engineering Progress

IT is scarcely possible to read a description of a new hydro-electric project, in these days, without learning of some new development in civil engineering. A relatively static condition which extended over many years appears to have given way to a buoyant acceleration of research and practical experiment in all parts of the world, and this augurs well for the future. New processes which are being actively developed in the many hydraulic and civil engineering research centres will inevitably cheapen—and at the same time improve—the hydro-electric installations of the future.

Mention can be made here of only a few aspects of this fertile field of progress. Prestressed concrete, used over the last decade in buildings, is now taking its place in the construction of dams. It results in lighter, more elegant structures, needing less bulk of concrete and therefore costing less, in spite of the additional expense of the prestressing procedures. Allied to this development there is the vast field of measuring and testing instrument research, which enables non-destructive testing to be carried out on all types of concrete structure so that a new procedure such as prestressing can be embarked upon with complete confidence. Vibration tests on a prismatic test piece, or measurements of the speed of propagation of an elastic wave in a test piece or in the structure itself, are both methods which have been greatly improved in recent years, and now give results which have been confirmed to be of great accuracy and importance. Radio-active isotopes, now available freely in many countries—and in particular in Great Britain—from nuclear physics laboratories, have been found extremely useful in testing the homogeneity of concrete structures by way of non-destructive testing, and this method has the advantage of enabling photographic reproductions to be obtained of tests on actual structures, which can then be compared with tests taken on the same structures perhaps a year or more later to show up any possible ageing effects.

Extensive Italian tests by X-ray methods have yielded valuable information on the internal stresses of reinforced concrete beams of various types, including those of prestressed construction.

Photo-elastic methods have been used to a much greater extent in recent years for the examination of the stresses on the metallic portions associated with sluice gates, valves, pressure conduits, draft tubes, and the rotating parts of water turbines. Extraordinarily interesting stress pictures have been obtained, which have resulted in radical changes in design and consequent improvement in overall reliability. Extensive tests have been carried out on the electrical curing of concrete by means of passing current through resistances embedded in the structure or through the reinforcing, and although the results have been favourable much work still remains to be done in this field.

The vibration of concrete is constantly being improved and research is taking place into the best frequencies and power inputs required for this purpose. Considerable improvements in concrete quality due to better methods of vibration, with less expenditure of energy, may confidently be looked for in the next few years.

In regard to shuttering, researches of a more directly practical nature than those just mentioned are taking place into the use of the plastic materials which are now seen in every field of human activity; American civil engineers are using wooden shuttering sections covered with a plastic coating which enables the same sheet to be used up to 200 times.

On sites where the usual types of aggregate and even pure water are difficult to obtain, or where great expense is involved in their transportation, engineers have made bold experiments in using locally available materials; for example, in the Pacific Islands civil engineering structures have been successfully constructed using coral and sea-water to form a concrete of surprisingly good quality.

Aerial and geophysical methods of surveying (each being constantly improved together with many electrical devices enabling ever-greater accuracy to be obtained in the determination of the nature and location of sound foundation ground, mean that the initial

planning stages of large projects can continually be shortened, while at the same time greater certainty in planning can be achieved.

The use of reduced-scale models, once felt to be more of theoretical interest than of practical value, has now taken its place as the most important preliminary operation in the majority of new hydro-electric projects; and the exhaustive work carried out in French, Italian, American and British laboratories in this field has meant that an ever-increasing amount of reliance can be placed on the results of such tests. Moreover, the scope embraced by the activities of these laboratories is continually increasing; for example, a French hydraulic laboratory has been called in to advise a South American state on the best means to be adopted to increase the capacity of one of the principal ports, and to ensure that any structures built for this purpose will not result in the navigable waterways being silted up or in bars being created where none existed before.

There is one field of hydraulic research in which new and particularly exciting prospects are opening out. It relates to tidal power, and although there have been many scores of reports on major tidal schemes in America, Great Britain and France, none has yet reached the stage of beginning practical operations. We now read, however, in the Annual Report of Electricité de France for 1953 that the second general plan for energy development in that country includes a definite project for the Rance scheme, which has been the object of study for many years by French civil engineers. It is not clear at the moment, in the disturbed state of French political affairs, as to whether the credits allocated for the second plan (following the Monnet plan) have been finally allocated by the French Government; but the programme includes—as well as the execution of the first stages of the Rance tidal power scheme—four groups of projects including two on the Rhone, one on the Rhine, and one each in the basins of the Isère and the Durance, which altogether will produce 6·5 milliards of kilowatt hours per annum.

British Electrical Power Convention

THE seventh British Electrical Power Convention will be held at The Dome, Brighton, this year, from June 27 to July 1, under the presidency of Sir Harry Railing. This convention is representative of all the principal electrical organisations, 38 in number, and will be attended by over 2,000 people from all parts of the country. In conjunction with the convention proper, which will consist of an interchange of views based on a number of papers that are being presented, there will be an exhibition of electrical appliances of all kinds, occupying 23,000 sq. ft. of ground space.

None of the papers to be presented will have much bearing on hydro-electric power, but that by J. Eccles, C.B.E., who deals with "The Generation of Electricity in Great Britain—A Ten Year Forecast" will refer to pumped-storage schemes and the part they may be expected to play in the future, particularly in regard to the development of atomic energy. Other papers which concern all branches of the electrical industries will touch on the opportunity they offer as a career. The electrical industries are expanding rapidly and the means of obtaining the necessary manpower need to be constantly reviewed. The present position in this vexed matter will be considered in papers presented by Sir Henry Self, K.B.E., who will speak of the opportunities the electricity supply industry offers, and by S. E. Goodall, M.Sc., who will speak for the manufacturing side of the industry.

Paulo Afonso Project, Brazil

IN our March issue, page 82, we referred to the Paulo Afonso hydro-electric project as being "the largest post-war power development in Brazil." When making this statement we had unfortunately overlooked the 330,000 kW Nilo Peçanha plant (formerly Forçacava) of the Brazilian Traction, Light & Power Co. Ltd. in the State of Rio de Janeiro. This hydro-electric plant is also a post-war development, and has been in full operation for some months. The Nilo Peçanha station and its water supply system were described in the article we published on the Paraíba-Piraí diversion, page 287, August 1953 issue.

The Jordan Scheme

MR. Eric Johnston, who has been investigating the possibilities of joint exploitation, under American sponsorship, of the waters of the Jordan and Yarmuk rivers, is stated to have reached a provisional understanding with the Arab Governments concerned.

Mr. Johnston's initial talks with the Israelis on his latest arrival in the Middle East—this makes his third visit to the area in connection with the Jordan development scheme—were not very promising. The Israelis have been standing out for a larger share of the water, claiming that Mr. Johnston's " water duty " estimates were exaggerated and that the aggregate of water proposed for Jordan, which has the major share of the catchment area, had been calculated without taking into account the underground water reserves of the unirrigable areas, which included roads and habitations. They also claimed that the water they had already drawn off from the Jordan as a result of the drainage schemes for the Huleh lake area should not be counted as part of their share under the international scheme. These are scarcely political issues and the matter would thus appear to be approaching solution on purely technical considerations, as is to be highly desired. Mr. Johnston is a skilled negotiator and there is now some expectation that this valuable scheme will be brought into being.

British Columbia Developments

A RECORD construction budget, involving an expenditure of $38.5 million is foreshadowed for B.C. Electric during the current year. In announcing this programme, Mr. Grauer, the President, stated that the lion's share of this capital fund would go towards expanding the system's electric facilities. Hydro-electric projects, mainly at Seton, Bridge River, and Choakamus River would claim over $12 million, and new substations in the Lower Mainland, together with the expansion of existing ones, would require $7.6 million. Electrical extensions, chiefly for connecting up new customers, would cost nearly $4 million and the expansion of the Lower Mainland's high-voltage transmission system was estimated to cost $3.4 million. The new submarine circuit connecting Vancouver Island to the Mainland electrical system was another item to which Mr. Grauer referred and gave the cost as nearly $1.1 million.

British Export of Hydro Equipment

IN reviewing the activities of Associated Electrical Industries Limited during the year 1954, Lord Chandos, the chairman, referred to the fact that the organisation had shipped rather more than £28 million worth of equipment overseas. This impressive total included some 370 MVA of waterwheel generators which were sent to Spain, Norway, India and New Zealand. Two further contracts were also obtained in the Canadian market, the first for 138 MVA of water-turbine-driven alternators for the Bersimis-Lac Casse project of the Quebec Hydro-Electric Commission, and the second for two 33 MW steam-driven alternator sets for the Manitoba Hydro-Electric Board. These were Metropolitan-Vickers machines. The British Thomson-Houston Ltd. also continued their advance in this market by securing a contract to supply six 230 kV, 7,500 MVA oil circuit breakers to British Columbia.

Progress in Spain

A BOOKLET sponsored by the Higher Council of Industry and entitled "Momento Actual de la Industria en España" indicates the remarkable progress that has been made in power developments in recent years. In the district of Avila, for instance, agriculture now has the advantage of electrical power derived from Saltos del Alberche and certain stations on the Iberduero. Active steps are now being taken to construct a 200 MV transmission line between San Esteban and Madrid through Puebla de Sanabria. This line, belonging to Saltos del Sil, will be 419 km. in length and will make energy produced in Galicia available to the capital.

It is now considered that there are no obstacles to the utilisation of a site on The Cares, near Arenas de Cabrales, for the development of water power. A power station having two vertical sets is projected, capable of generating 35 million kWh per annum. The turbines and generators, together with certain ancillary equipment, will be purchased abroad, but the civil engineering work and the manufacture of the other equipment will be undertaken by Spanish firms.

A Notable Tunnelling Achievement

THE number of tunnelling records claimed recently suggest that modern methods and equipment are being fully exploited and remarkable advances are being made. The latest record was claimed to be established during the cutting of the Achany-Inveran tunnel on the Loch Shin hydro-electric project for the North of Scotland Hydro-Electric board. Between Sunday, January 30th, and Saturday, February 5th, a team on the Inveran heading advanced 215 ft. in granite working on a rock face of 16 ft. equivalent diameter. The tunnel will be four and two-third miles long when completed. Drilling was done from a gantry travelling on an 8 ft. gauge rail and burn cuts were used for blasting. About 1,800 cu. yds. of rock were mucked out.

Eight Atlas Diesel RH754 rock drills were used with Swedish drill steels, while the mucking operations were carried out by two Eimco loaders. The tunnelling team worked in two 12-hour shifts a day. Each round averaged 50 holes about 10 ft. 3 in. deep. An average of 290 lb. of polar ammon gelignite was used per round and blasting was carried out with I.C.I. gasless delay detonators—an average of 49 per round. A total of 6,772 lb. of gelignite and 1,185 detonators were used during the week. Drilling time occupied 1 hour 20 minutes, charging and blasting 1 hour, ventilation and re-entry time ½ hour, and mucking time 2¾ hours. The breakdown of the tunnelling crews was one shift boss, eight machine men, two loader operators, two panel labourers, two loco drivers, three tip men, and nine plate layers who worked the day shift only. This project is being carried out by the George Wimpey Co. Ltd.

American Order for Italy

AN Italian firm has been awarded an electrical equipment contract by the U.S. Army Corps of Engineers. Industrie Electtriche di Legnano won a 137,351 dollars contract to supply three 12-16 MVA three-phase transformers to be installed at Cheatham Lock and Dam in Tennessee. The bid was understood to be 13·5 per cent. under the lowest American offer of 156,028 dollars.

Lebanon Tenders

IT is understood that tenders will be invited shortly for the first stage of a £46 million hydro-electric power and irrigation scheme in the Lebanon. Experts of the World Bank who have investigated the scheme during the last two months have informed the Lebanese Government that they recommend a 27 million dollar loan to help to finance the initial stages of the project. This is expected to include a hydro-electric power plant, with a capacity of between 70 and 80 MW, which will require the construction of a big dam and a 10-mile-long water tunnel on the Litani River. Ultimately, the country's electricity output will be raised to 600 million kWh, or five times the present production. The entire project is expected to be finished in all its stages by the end of 1961.

Iraq Expansion

THE Iraq Government Development Board is to expand electricity generation to the tune of 500 MW, costing £39 million, in five-year stages over the next 20 years. In the Lesser Zab River district an initial plant of 30 MW will use natural gas from Kirkuk oilfields as fuel, and the project will include distribution and transmission stations to four northern provinces.

New Canadian Proposal

A NEW proposal for a 30 million dollar storage dam on the Arrow Lake system is being considered by the British Columbia Provincial Government. Since the Kaiser Aluminium and Chemical Corporation appears unable to finance the dam at less than 7¼ per cent. interest and the Government could do it for 4·1 per cent., the new proposal is for the Government to undertake the construction and to receive extra returns from Kaiser Aluminium. The corporation is looking for water storage to increase production of power at U.S. hydro-electric stations during the low-flow period in British Columbia.

Present Trends in the Design of Pressure Tunnels and Shafts

An abstract is given of a paper presented to the Institution of Civil Engineers by Charles Jaeger, Dr ès Sc. Techn., the text having been modified in places in the light of contributions made to the discussion.

PART FOUR

THE grouting pressure p' behind the concrete lining should prestress it to such an extent that no fissure can develop when the water pressure p is applied. The grouting pressure behind the steel lining should make sure that no large voids remain behind the steel, even when the tunnel is emptied at lowest temperature. A reasonable stiffening of the steel plates against buckling should be produced. In many cases the grouting pressure p' will exceed the external water pressure and the steel linings will be designed accordingly.

The strains and stresses in rock, concrete, and steel resulting from grouting should be estimated.

Testing of Pressure Galleries: Water Seepage

Most lined pressure galleries are tested after construction. When the construction of the steel-lined pressure shaft at Oberaar (Grimsel) was complete, it was filled with water and subjected to a pressure test, with a maximum pressure of 40 atmospheres at the middle of the shaft. This corresponded to 66·8 atmospheres at the base of the shaft, which was equivalent to working pressure plus allowance for waterhammer at the base of the shaft. The volume of the water introduced for a given rise in pressure was noted and hence the stress in the steel lining was deduced. It was found to be 483 kg. per square cm., corresponding to a pressure of 40 atmospheres and about 800 kg. per square cm. for 65 atmospheres. It was also computed that the steel lining was carrying a quarter of the total load and the surrounding rock three-quarters. It is also planned that the pressure shaft will be tested periodically for watertightness, and the intervals between tests will range from six months to possibly three years if results are satisfactory.

The inclined pressure gallery of Gondo is in two parts; the lower part below level 1085 is steel-lined, the upper part between level 1085 and 1289 (next surge level) with a maximum head of 204 metres is concrete-lined. All the steel pipes to be used as lining for the lower part were tested in the works.

During the final pressure tests on the completed shaft, a water loss of 10 litres per minute was measured for the total length, including the unlined section. For the steel-lined section only the loss was 5·7 litres per hour.

Talobre has referred to the possibility of testing the watertightness of small drill holes in order to get an idea of the water losses in the whole tunnel. It is approximately true to say that the losses depend upon the tunnel length rather than upon its diameter.

Data on Large Pressure Shafts

Data on large pressure shafts have been summarised in Tables 1, 5 and 6. Table 5, part of which is from a publication by Talobre, gives general data on existing large steel-lined shafts. Table 1 compares the calculated stresses in the steel linings at the base of the shafts, assuming that no load is transmitted to the rock. These calculations are based on the data available from many publications. Table 6 refers to the maximum power concentrated in single large shafts.

The information contained in these three Tables is self-explanatory and illustrates the scope of modern projects better than any comment.

Underground Power Houses

The dimensions of underground power houses depend on the size and number of generating sets and the station arrangement. The turbines may be impulse wheels (Pelton) or reaction wheels (Francis or Kaplan), and of the vertical or horizontal type. The basis upon which rests the choice between the different types of turbines is essentially the same as for ordinary above-ground stations, but increased importance is attached to the volume of rock excavation. The vertical Francis turbine often requires less excavation for the valves and distribution pipes.

The transformers are sometimes arranged within the same general excavation as the generating sets, as at Innertkirchen and Isère-Arc. They can also be located in a separate excavation parallel to the main excavation, as at Vinstra and Soverzene, or nearby, as at Harsprånget. The last choice is an above-ground location, as at Krångede. A simple rule of thumb used by Italian engineers is that, if the length of the low-tension transmission cables is more than 250 to 300 metres, the arrangement with underground transformers is cheaper. Norwegian designers seem to favour placing the transformers underground, partly for military reasons.

The valves upstream of the turbines can be located inside the main excavation or in a special excavation upstream of the general turbine hall. This last arrangement is reserved mainly for high-head schemes.

Fig. 22 gives outlines of the principal designs which have been evolved, and Tables 7 and 8 summarise the main data of several well-known installations.

The technique of excavating the power house will depend on the rock, on its stability and strength, on the main direction of the stata, on the amount of water to be expected, on the cost of excavation, and on the constructional equipment which the contractor is prepared to use on the job. Italian contractors, who have relatively cheap labour available, will adopt techniques differing from those of Swedish or American contractors. But there is a definite tendency, in countries like France, Switzerland, or even Italy, for contractors to adopt Swedish or American plant and methods.

Normally, the excavation and the concreting of the

TABLE 5. DATA ON LARGE STEEL-LINED PRESSURE SHAFTS

Name	Country	Date of commission	Gross head : m.	Internal dia.: m.	Rock	No. of pipes	Discharge: cumecs	Gradient: tan α
Lavey	Switzerland	1950	42·5	5·8	—	3	200	—
Porjus	Sweden	1914	57	3·5-4·2	Granite	7+2	90	Vert.
Niagara	U.S.A.	1920	60	4·7	Limestone	1	—	Vert.
Krångede	Sweden	1936	60	5·5	—	4	—	Vert.
Niva	U.S.S.R.	1949	74	4·5	—	4	4×62·5	Vert.
Castillon	France	1949	90	3·4	Good limestone	2	72	0·35
Cordéac	France	1946	92·5	2·9-3·8	Limestone	1+1	29+28	0·71-0·02
Châtelot	France	—	91	3·0	Limestone	1	40	0·702
Piage-de-Vizille	France	1950	142·4	3·5	—	1	45	0·549
Isère-Arc	France	1953	153	2-3·7	Gneiss, mica-schists	2	2×50	Vert.
Salarno	Italy	1945	162	1·6-2·0	—	1	3	Vert.
Boulder	U.S.A.	1936	177	9·14-7·62 3·96-2·59	—	—	—	1·00 0·70
Valabres	France	1954	195	2·2	Limestone	1	15	0·85
Sillre	Sweden	1923	197	1·85	—	1	—	0·19
Soverzene	Italy	1948	285/225	2·55	—	2	2×20	3·00
Brevières	France	1951	232	3·75	Quartzites	1	50	0·02
Cedegolo	Italy	Constr.	234	2·60	—	—	—	Vert.
Rossaaga	Norway	Constr.	245	3·3-2·8	—	1	34	1·00
Brommat	France	1933	260	4·0-3·0 -2·6	Granite	3	—	Vert.
Bersimis	Canada	Constr.	267	9·45 3·06-2·36	—	1 8	416 52	Horiz. 1·19-0·01
Wassen	Switzerland	1949	281	2·4-2·2	—	2	2×42	0·67-0·013
Castelbello	Italy	1949	294	3·25-2·80	—	1	21	0·85
Verbano	Switzerland	1953	297	3·0-2·80	—	1	44	—
Mera I	Italy	1948	330	2·55-2·25	—	1	—	0·70
Snowy Mountain T I	Australia	Constr.	336	3·65	—	2	2×64	Vert.
Rodund III	Austria	1943	339	3·2-3·05	—	1	60	0·58-0·0
Cubatão	Brazil	Constr.	720·4	3·25	Granitic gneiss	1	75	0.90
Tafjord II	Norway	Constr.	396	1·75	—	1	60	0·93
Calancasca	Switzerland	1949	404	1·49	Gneiss	1	6	0·80
Achensee	Austria	1927	406	2·3	Limestone (Dol.)	1	—	1·00
Cañon del Pato	Peru	Constr.	420	1·8	Granite	1	28	Vert.
Mauvoisin-Fionnay	Switzerland	Constr.	459	2·4	Calcar. schists	1	23	—
Handeck II	Switzerland	1950	463	2·25-2·15	Granite	1	30	0·61-0·15
Pallazeno	Italy	1926	527	1·8-1·5	Gneiss (mediocre)	1	8·4	0·70
Oberaar	Switzerland	1953	531	1·65	—	1	—	—
Handeck I	Switzerland	1932	546	2·3-2·1	—	1	8	0·72-0·08
Santa Massenza	Italy	1949	600	2·6-2·5	Limestone (excellent)	1	20	0·85
Gerlos	Austria	1943	620	2·2-1·6	Limestone (fissured)	2 1	2×35 12	0·52
Lyse	Norway	Constr.	630	2·0	Granite	—	—	0·70
Montpezat	France	1953	643·5	2·6	Granite	1	22	0·467
Innertkirchen	Switzerland	1940	672	2·6-2·4	Granite and gneiss	1	40	0·616 0·583
Rovesca	Italy	1926	720	1·2	Schists, gneiss	1	3	0·123 0·70
Mese	Italy	1926	758	1·8	Gneiss (mediocre)	1	—	0·70
Kemano	Canada	Constr.	790	3·35	—	4	4×62·5	1·11
Pfaffensprung	Switzerland	Proj.	823	2·5	—	1	4×30	0·70-0·60
Grande-Dixence-Fionnay	Switzerland	Constr.	872	3·0-2·8	—	1	45	—
Albigna	Switzerland	Proj.	1046	1·5	—	1	—	—
Roselend	France	Proj.	1171	3·0	Schists	1	50	0·90

arched roof of the power-house excavation will be given first priority, and then the excavation work will proceed downwards over the whole width of the power house, as at Lavey,[55, 56] or in trenches along the walls, leaving a central core to be excavated later, as at Innertkirchen and Verbano.

The walls will usually be lined with concrete, the concrete adhering directly to the rock. Norwegian engineers prefer to leave a space of from ½ to 1 metre between the rock and the walls and roof. Thorough ventilation is necessary in order to keep the rock dry. This technique has also been used in countries other than Norway and Sweden (for example, at Lavey[52] in Switzerland). In solid granite the walls may be without any lining and the bare rock is visible, as at Hojum in Sweden. Westerberg mentions one case where the arched concrete roof has been omitted, the rock being covered with expanded metal and a gunited mortar lining. Norwegian engineers favour designs where the concrete arched roof, with or without ribs, is at some distance from the rock roof.

A rule of thumb given by Norwegian engineers proposes that the overburden above any power-house excavation should be twice the width of the excavation, with a minimum overburden of 30 to 35 feet. Cases are known (for example, Clachan in Scotland) where

the power house was excavated by the cut-and-cover method. At Clachan, this method was cheaper than a conventional power-house design above ground level. For large power stations, where the strata of the rock are suitable, the longitudinal axis of the power house should be at an angle of from 20° to 30° to the axis of the pressure shaft, since this arrangement is favourable for the design of the distribution pipes.

When water is expected along the walls, the wall may be made double with provision for drainage between the skins. If rock pressure is expected to develop, specially reinforced walls are essential for the stability of the excavation.

The walls of the power house at Lumiei are arched in the horizontal direction and comprise segments of cylinders with vertical axes. To deal with higher rock pressures a cylindrical roof and walls of elliptical cross-section are favoured. In the well-known power house of Santa Giustina the elliptical crosss-section is reinforced by the heavily reinforced generator floor, which act as a horizontal strut against the horizontal component of the rock pressure.[72, 74] The Peccia and Cavergno power houses (Maggia[69]), with horizontal Pelton wheels are of parabolic shape to withstand the rock pressure (Fig. 22).

The designers of the power house of Ahrzerouftis thought that a semi-circular roof and thick slanting lateral walls would provide additional safety. The French designers estimate that for the worst possible conditions of pressure, the stresses in the arched roof are not more than 65 kg. per square cm. and in the lateral walls 93·8 kg. per square cm.

There is a tendency, when designing underground power houses, to choose the station arrangement giving the minimum excavation. The generator support and the spiral casings are developed along the conventional lines adopted for above-ground stations. Isère-Arc shows one interesting alternative. The conventional cylindrical generator supports for the vertical Francis turbines are replaced by hemi-spherical cupolas, whose diameter is greater than the diameter of the spiral casings. The erection of a turbine was not begun until the civil contractor had built the cupola, so that civil engineering and turbine erection did not interfere with each other.

Vertical access shafts were favoured some years ago but modern contractors prefer longer inclined tunnels which can be traversed by diesel lorries.

Mainardis, Heggstad, and others have emphasised the importance of the electro-mechanical equipment required for underground stations, such as the types of generator, cooling system, and aeration to be adopted, and the advantages of having the transformers underground or on the surface. Further details of underground power houses are summarised in Tables 7 and 8, and in Figs. 21 to 24.

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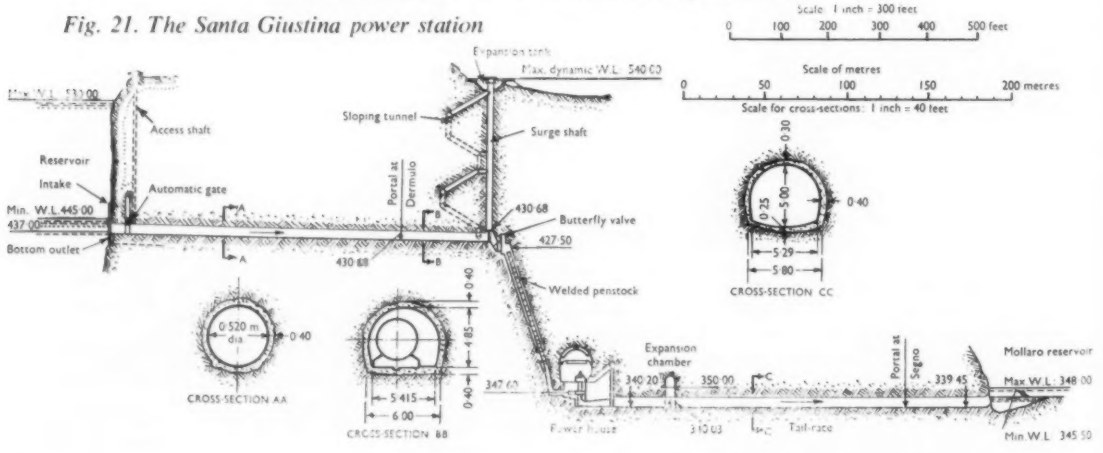
TABLE 6. WATER-HORSE-POWER OF LARGE SHAFTS

Year	Power station	Head: m.	Head: ft.	Discharge per shaft: cumecs	Discharge per shaft: cusecs	Power per shaft: h.p.	Total power: h.p.
1942	Innertkirchen	672	2200	40	1410	325000	325000
1947	Lumiei	480·6	1580	16·5	583	77000	77000
1951	Santa Giustina	183/95	600/311	22·2/15·9	780/562	142500	142500
1952	Santa Massenza	590/460	1940/1505	70	2470	200000	400000
1952	Handeck II	463	1515	30	1060	154000	154000
1953	Isère-Arc	152	500	50	1770	90000	180000
1954	Montpezat	634	2080	22	779	162000	162000
1954	Kemano	790	2597	68	2400	560000	2240000
Constr.	Bersimis	253	830	416	14700	1600000/ 200000*	1600000
Proj.	Roselend	1171	3840	50	1770	660000	660000
Proj.	Pfaffensprung	820	2690	30	1060	245000	980000
Constr.	Grande-Dixence-Fionnay	872	2860	45	1590	390000	390000
Constr.	Mauvoisin-Fionnay	459	1400	23	815	170000	170000
Constr.	Snowy Mountain T 1	336	1105	128	4530	270000	540000

*The main shaft, 570 feet long, divides into eight penstocks.

Fig. 21. The Santa Giustina power station



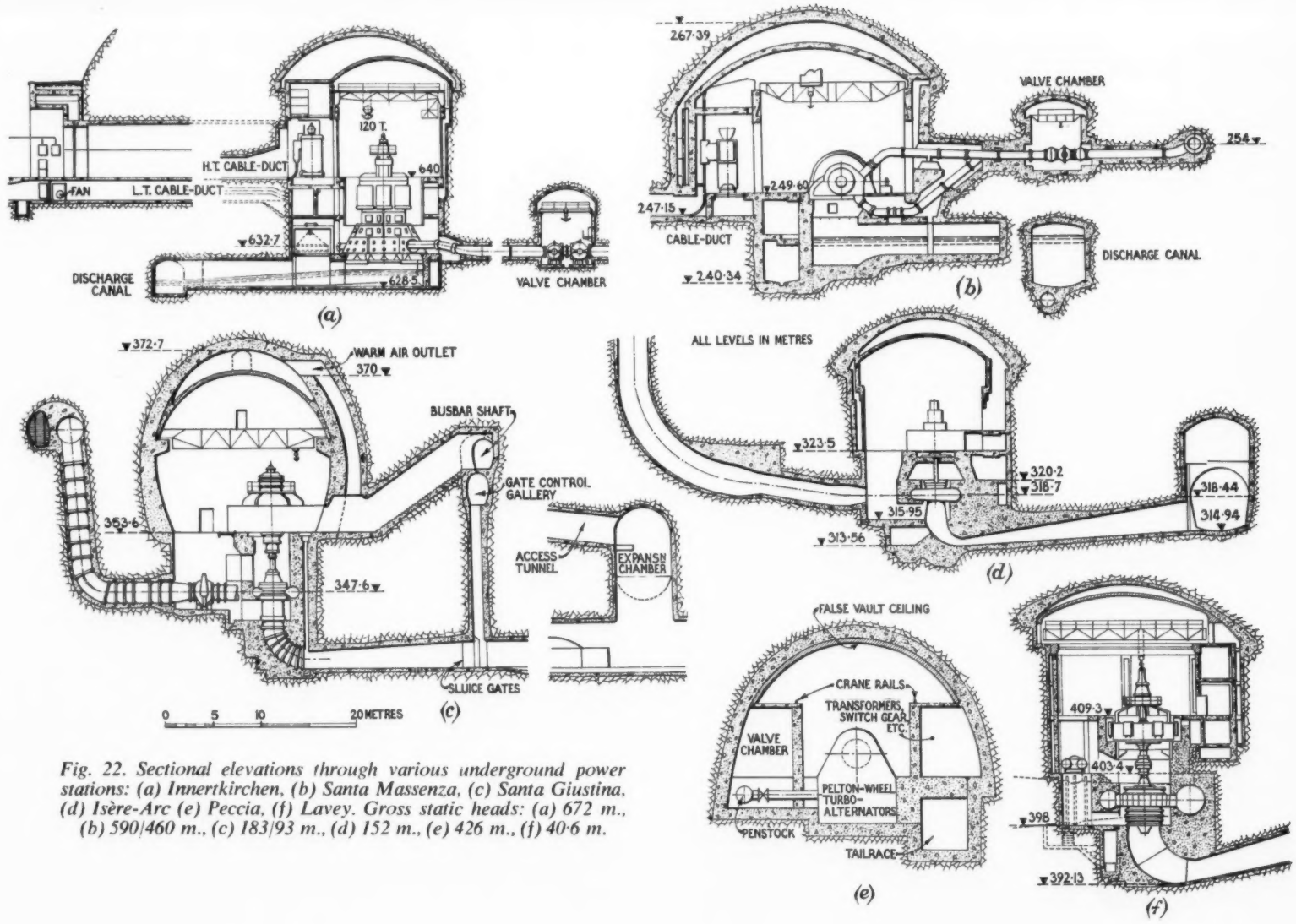


Fig. 22. Sectional elevations through various underground power stations: (a) Innertkirchen, (b) Santa Massenza, (c) Santa Giustina, (d) Isère-Arc (e) Peccia, (f) Lavey. Gross static heads: (a) 672 m., (b) 590/460 m., (c) 183/93 m., (d) 152 m., (e) 426 m., (f) 40·6 m.

TABLE 7. DATA ON UNDERGROUND POWER HOUSES

Date of commission	Power station	Country	Capacity: kW	Gross head: ft.	Turbines: h. = horizontal v. = vertical	Volume: cu. yds.	Excav. for transf. or valve house, etc.: cu. yds.	Volume of power house per kW installed: cu. yds.
1910	Porjus	Sweden	60,000	183	8 Francis, h.	35,000	6,000	0·58
1932	Brommat	France	186,000	855	6 Francis, v.	60,000	16,000	0·32
1942	Innertkirchen	Switzerland	210,000	2,200	5 Pelton, v.	59,000	20,000	0·28
1947	Lumiei (Ampezzo)	Italy	58,500	1,465	3 Pelton, h.	33,000	—	0·565
1948	San Giacomo	Italy	200,000	2,140	3 double Pelton, h.	37,000	5,000	0·19
1948	Soverzene	Italy	220,000	870	4 Francis, v.	85,500(*a*) 102,000(*b*)	16,500(*a*)	0·390(*a*) 0·465(*b*)
1949	Mar	Norway	180,000	—	—	60,000	—	0·334
?	Vinstra	Norway	180,000		Francis, v.	30,000	8,170	0·167
1949	Provvidenza	Italy	150,000	838	3 Francis, h.	44,000	3,000	0·29
1950	Lavey	Switzerland	76,000	133·5	3 Kaplan, v.	54,500	7,200	0·715
1952	Handeck II	Switzerland	114,000	1,520	4 Pelton, v.	39,000	—	0·34
1951	Santa Giustina	Italy	108,000	560	3 Francis, v.	40,000	—	0·37
1951	Harspranget	Sweden	288,000(*c*) 380,000(*d*)	353	3 Francis, v. 4 Francis, v.	63,300 79,000	30,000(*e*)	0·22 (*c*) 0·206(*d*)
1951	Ahrzerouftis	Algeria	66,500	1,125	2 40,000 h.p. Pelton, v. 1 7,500 h.p. Francis, v.	44,000(*f*) 80,000(*g*)	—	0·66 1·20
1951	Santa Massenza I	Italy	302,000	1,940 to	6 Pelton, h.	203,000	10,900(*h*)	0·92
	Santa Massenza II	Italy	25,500	1,505	2 Francis, v.			
1952	Monte Argenta	Italy	66,000	164	3 Francis, v.	21,000	8,000	0·32
?	Montorio	Italy	100,000	845	3 Francis, v.	29,000	1,000	0·29
1952	Verbano	Switzerland	100,000	973	4 Francis, v.	33,000	—	0·33
1953	Isère-Arc	France	135,000	500	4 Francis, v.	68,000	—	0·50
1954	Montpezat	France	116,000	2,080	2 double overhang Pelton, v.	26,300	—	0·226
1954	Kemano	Canada	835,000(*j*) 1,670,000(*k*)	2,597	8 Pelton, v. 16 Pelton, v.	273,000 473,000	— —	0·327 0·284
Constr.	Fionnay	Switzerland	127,500	1,555	3 Francis, v.	27,000	1,800	0·21

Notes. (*a*) Without transformer house. (*b*) Including transformer house. (*c*) First stage. (*d*) Second stage. (*e*) For transformer house. (*f*) Useful excavation. (*g*) Including 10-foot thick walls and roof. (*h*) For valve house. (*j*) First stage. (*k*) Second stage.

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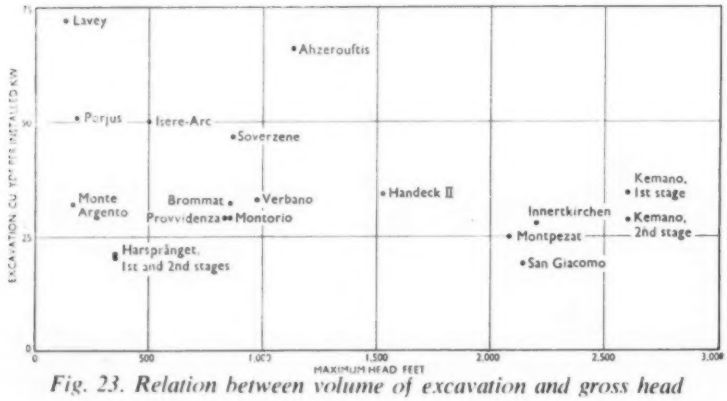

Fig. 23. Relation between volume of excavation and gross head

TABLE 8. DIMENSIONS OF SOME LARGE UNDERGROUND POWER STATIONS

Power house	Head: metres	Total height*: m.	Total width: m.	Total length: m.	Crane span: m.	Crane capacity: tons	Turbine horse-power	Distance between turbine centres: m.	Position of transformers	Valves
Kemano, 1st stage	790	42·4	24·8	195·5	15·25	2 × 225	8 × 140,000	18·3	Inside main excavation	Special excavation
Kemano, 2nd stage		42·4	24·8	344	15·25	—	16 × 140,000	—	Inside main excavation	Special excavation
Innertkirchen	672	26·85	19·5	96·70	10·8	120	5 × 56,000	14·50	Inside main excavation	Special excavation (28-ton crane)
Montpezat	634	23·2	16·1	50	13·5	2 × 135	2 × 81,000	—	Outside	?
Santa Mazzenza I and II	590/460	28·0	28·8	192·7	14·2	—	4 × 80,000 2 × 40,000 1 × 25,000	18·0	Inside main excavation	Special excavation
Cavergno (Maggia)	590	21·5	28	—	11·6	—	2 × 27,500	—	Inside main excavation	Inside main excavation
Lumiei	480·6	24·2	15·4	71	12·0	—	3 × 25,500	—	Outside	Special excavation upstream of main excavation
Fionnay	471	24·30	12·68	49·8	8·2	90	3 × 72,000	11·2	Outdoor	Special excavation
Handeck II	463	25·55	16·8	79·25	10·70	—	4 × 41,000	14·0	Inside main excavation	Special excavation
Peccia (Maggia)	426	21·5	28	—	11·6	—	2 × 23,500 2 × 11,600 2 × 40,000	—	Inside main excavation	Inside main excavation
Ahrzeroufftis I and II	345	22·4	20	67	—	120	1 × 7,500	—	Outside	
Vinstra	?	27	13	73	11	—	4 × 60,000	11	Inside special excavation	Straight flow valves, inside
Bersimis	336	28·5	19·4	171	18·4	2 × 200	8 × 175,000 8 × 200,000	16·8	Inside main excavation	
Snowy Mountain T 1	334	28	17	92	14·5	—	4 × 134,500	12·8	Inside special excavation	Straight flow valves, inside
Soverzene	265	35·1	25·5	73	17	—	4 × 72,500	14	Inside special excavation	Inside main excavation
Brommat	260	31·4	21·8	?	11·5	140	6 × 40,000	—	Outside	Inside main excavation
Santa Giustina	183/95	29·5	17	61·3	13·7	—	3 × 47,500	12·8	Outside	Inside main excavation
Isère-Arc	152	31·6	16·8	56·25 109†	13	—	4 × 45,000	10	Inside prolonged main excavation	Inside main excavation
Harspranget, 1st stage	108	33 43‡	183	100	—	2 cranes	4 × 127,000	20	Inside special excavation	—
Lavey	40·6	31	21	64	14·5	2 × 60	3 × 33,500	14	Outside	Separate excavation

* Not including draught-tube height. † Including transformers and workshop. ‡ Including draught-tube height.

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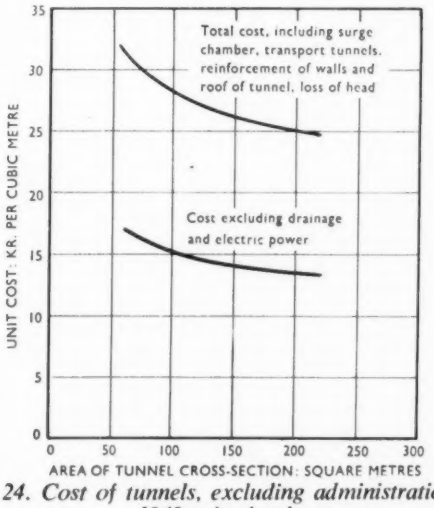

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Fig. 1. Le Marinel scheme, the Lualaba river upstream of the dam site

Upper-Katanga Developments

An account is given of various schemes in the Province of the Belgian Congo.

THE hydro-electric developments in operation or in progress in this south-eastern Province of the Belgian Congo, are the logical consequence of the exploitation of huge deposits of copper ore in a region particularly rich in utilisable water resources. Following the discovery of these deposits in 1892, the yearly production had grown from modest beginnings to 1,000 tons in 1911, and reached 192,000 tons in 1951; by the end of 1952, the aggregate output of the mines since the foundation of the Union Minière du Haut-Katanga (U.M.H.K.), had passed the 4 million ton mark. The copper ores available are, to a large extent, hydrous carbonates and silicates which, owing to the scarcity of fuel, are won and treated mainly by

Fig. 2. Levelling in progress at the powerhouse site, Le Marinel

electrolysis, a process which requires the production of large amounts of electric energy. During the first twenty years, that is to say until 1930, the mines had to rely mainly on local thermal power plants, although as long ago as 1907 the U.M.H.K. had engaged a team of Swiss experts to explore sites suitable for hydro-electric development in the neighbourhood of the mining centres. The Haut-Katanga Province, which covers an area 3½ times as great as England (465,000 sq. km.), is crossed by numerous tributaries of the Congo River flowing either from south to north or east to west and dotted with waterfalls or stretches of rapids which lend themselves particularly well to the establishment of hydro-electric stations. According to M. R. Bette's comprehensive survey, the utilisable hydraulic resources of the Congo Basin are estimated at about 13 million horsepower, of which more than two-thirds lie in districts exceeding 500 m. in altitude, so that the Katanga rivers alone could be developed to the extent of several million horsepower.

Fig. 3. First stage of constructional work for diversion channel, Le Marinel scheme

Developments on the Upper-Kantaga are divided into two groups:—the Lufira or eastern group, comprising the Francqui and Bia power stations; and the Lualaba, or western group, comprising the Delcommune and Le Marinel plants, the latter still being in early stages of construction. The main characteristics of these four stations are given in Table I.

Lufira Development

The Lufira River, whose catchment area covers 11·980 sq. km., has its source in the high plateau bordering on Northern Rhodesia, and flows, after a course of 300 km., into the Upemba and Kisale lakes on the Lualaba, constituting the Upper Congo River. The upper stretch of the Lufira is very uneven; there is a

Fig. 4. Francqui scheme, Madingusha, showing Cornet falls before the development of the Lufira river

TABLE I

Characteristics		Lufira Group		Lualaba Group	
		Francqui	Bia	Delcommune	Le Marinel
Installed capacity	Turbines ..... h.p.	96,000	60,000	152,000	356,000
	Generators ..... kVA	77,000	46,800	120,000	276,000
Mean operating discharge, cu. m. per sec.		45·5	45·5	95·5	103·0
Number of generating units		6	3	4	4
Gross head ..... m.		114	60·5	77·05	185
Average output ..... kW		42,000	21,600	59,020	164,000
Yearly production ..... million kWh		368	190	516	1,430

drop of over 100 m. in two stages over a length of 600 m. near Mwadingusha, followed by a 10 km. stretch of rapids. The Kiubo Fall, about 100 km. downstream, has a height of 40 m.; in addition, there is a single-stage fall of no less than 300 m. on the Lofoi, a small tributary of the Lufira rising in the Kundelungu mountains. The flow of the Lufira is characterised by a wide difference between the low-water period in October, at the end of the dry season (10 to 12 cu. m. per sec.) and the flood period in March-April at the end of the rains (250 to 300 cu. m. per sec.). The yearly mean flow is 45 cu. m. per sec., and the average run-off coefficient 0·1255.

Work on the Francqui plant, the first large-scale power station in Katanga, began in 1937 at the Mwadingusha falls, now renamed Cornet falls. At the outset the installation comprised a concrete gravity overflow dam, 9 m. in height and 550 m. long, creating a storage of 35 million cu. m. A surface intake on the left bank, with four 6 × 3 m. intake gates, fitted with coarse trashracks and stoplogs, enables a 3 m. layer of water (20 million cu. m.) to be utilised. There is an open supply canal 700 m. long concrete lined throughout and a forebay equipped with a fine trashrack and rake. Three 3 × 3 m. gates control the flow to the two penstocks, which are of steel and are 2·5 to 2·2 m. in diameter, 300 m. long and welded throughout. Each is fitted with a butterfly head valve 2·5 m. in diameter. The powerhouse, built along the bank of the river, is equipped with three 15,000 h.p. vertical-shaft alternators driven by Francis turbines operating at 375 revs. per min. and discharging 11 cu. m. per sec. each. A 6,600/120,000 V transformer station is sited 100 m. above the powerhouse, to which it is connected by a cable tunnel.

This installed capacity soon proved insufficient and in 1935 two 20 × 4 m. flood-gates were added to the dam, so as to increase the storage capacity to 70 million cu. m. A third penstock and two further 17,000 h.p. units were added in 1939 at the same time that the crest of the dam was raised 4 m. The capacity of the reservoir then reached 1,400 million cu. m. and the area increased to 450 sq. km. This huge reserve of water ensures the regulation of the river discharge practically to the full. A sixth 17,000 h.p. stand-by unit, now in course of erection, will complete the development of the Cornet falls, in-

Fig. 5. Francqui plant, Madingusha, dam and flood control gates

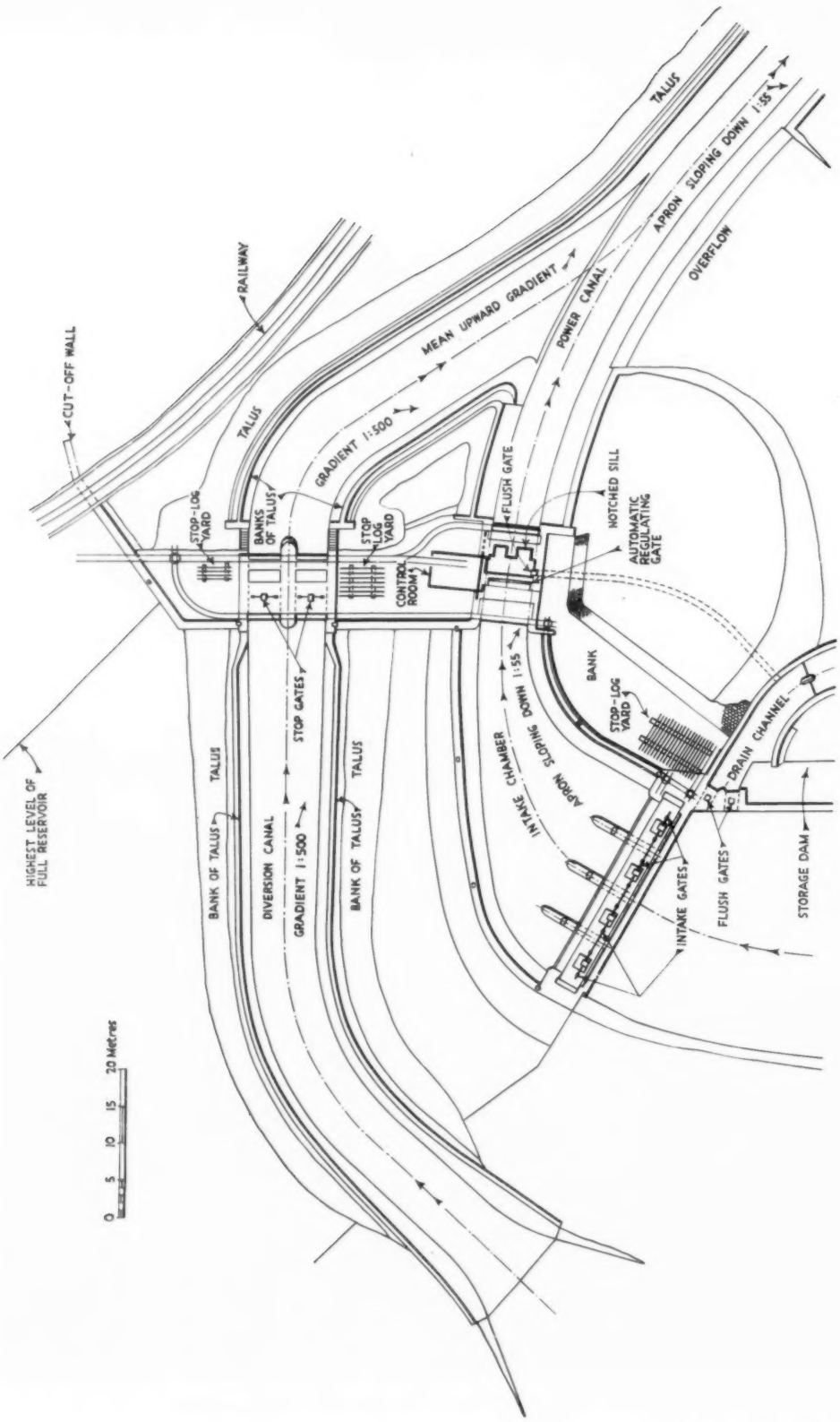

Fig. 6. Plan of intake works, Francqui station

creasing the installed capacity to 96,000 h.p. With each turbine passing an average of 12 cu. m. per sec., the plant will be able to operate with five generating units during the rainy months, when the flood gates have to be kept open. The distribution system comprises 425 km. of 120,000 V and 170 km. of 50,000 V lines.

An interesting feature of the dam is that after its heightening, the original triangular cross-section assumed a trapezoidal form. The heightening was effected from the downstream side without interrupting power generation; the whole of the downstream face was picked over and cut to hold the lugs of reinforced concrete blocks. In addition, extensive grouting under pressure was carried out through the whole of the heightened structure to strengthen the new constructional joints.

With the storage level raised to 4 m. above the level of the supply canal and forebay it was necessary to provide an automatic regulating gate at the head of the canal, or the canal banks would have had to be raised. This gate is controlled by the water level in the canal, and its opening is regulated in accordance with the turbine discharge rate and the level of the water in the reservoir. To provide against the catastrophic consequences of an untimely opening of this gate, the supply canal is provided with two long waste weirs which ensure the discharge of several hundreds of cu. m. per sec. without endangering the works.

The Bia power station gathers its head over a length of 3 km. and utilises a gross fall of 60·5 m., including the Koni rapids. Owing to the war, the constructional work, which was scheduled to begin in 1939, had to be postponed until 1945. The rock-fill dam, 19 m. high by 490 m. long at the crest, is provided with an emptying system consisting of a 30 m. high control tower and a 140 m. length of tunnel which enables the reservoir to be drawn down to the foot of the dam while evacuating, at the same time, the turbine discharge to the Francqui plant at the rate of up to 150 cu. m. per sec. The rock fill incorporated in the dam has an aggregate volume of 205,000 cu. m., and consists of hard, sound material drawn from nearby beds of quartzite. Flood control is ensured by a spillway, 160 m. in length, equipped with a gate for the removal of floating debris. The intake is of the same pattern as at the Francqui station, with four 4·5 × 3 m. gates designed for the utilisation of a 4 m. layer of water or 9 million cu. m. out of the 28 million cu. m. reservoir. The supply system, 1,250 m. in aggregate length, comprises a tunnel, 160 m. in length, and a syphon, both of which are 30 sq. m. in cross-section and which connect with the length of open channel. The forebay is equipped with a fine trashrack and rake, and three 2·6 by 3·4 m. safety roller-gates which are arranged to close automatically in the event of a burst in the corresponding penstock. There are three penstocks, 100 m. long and 2·9 m. in diameter. The powerhouse is similar in structure to that of the Francqui plant but the filling consists of rubblework instead of brickwork. It contains three 20,100 h.p. Francis vertical-shaft turbines having a speed of 333·3 revs. per min. The tail-race, 1,300 m. in length, comprises an afterbay, a free-flow tunnel, and a covered canal section followed by an

Fig. 7. Interior of powerhouse, Francqui plant; a sixth generating set is now being erected

Fig. 8. Delcommune scheme, Zilo; general view of dam shortly after filling of reservoir had started

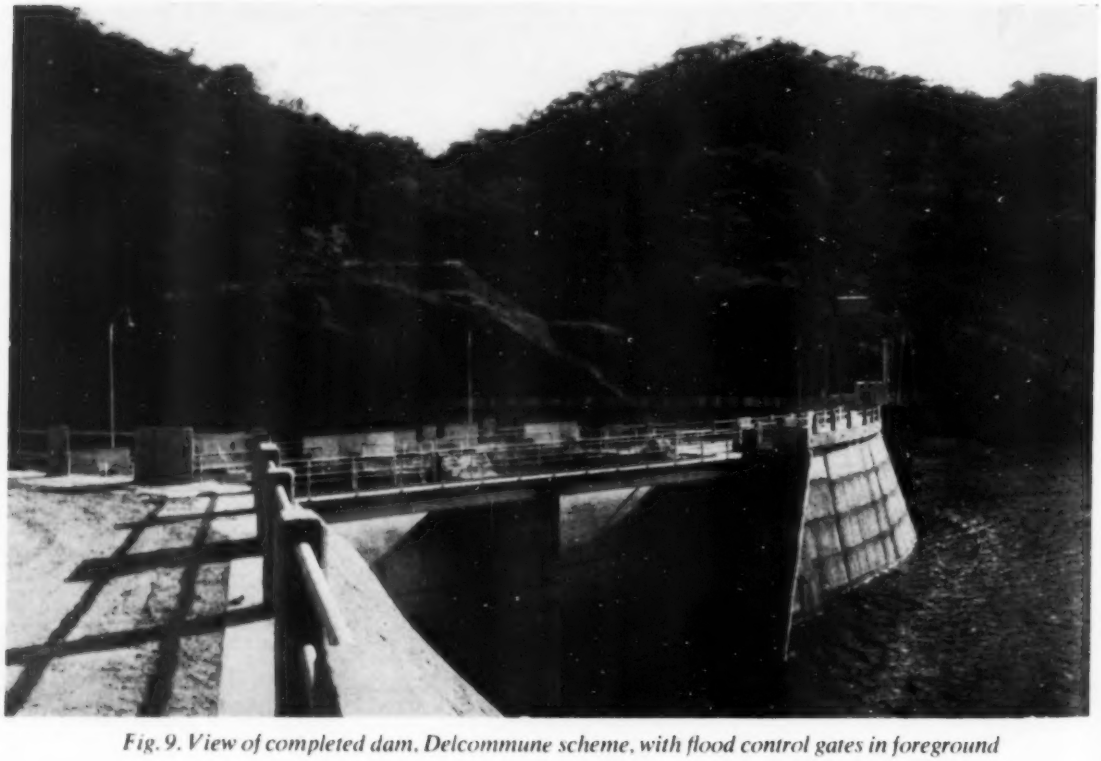

Fig. 9. View of completed dam, Delcommune scheme, with flood control gates in foreground

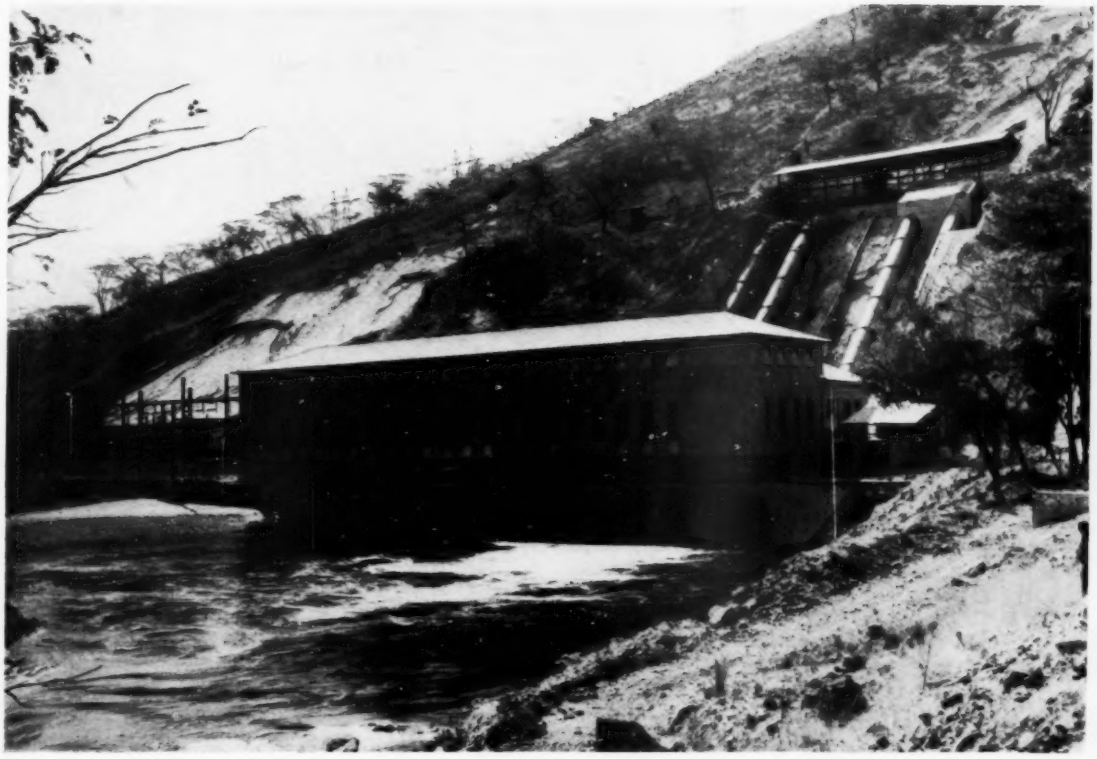

Fig. 10. Completed Delcommune powerhouse with first two generating sets in operation

unlined canal section. The 6,600/120,000 V transformer station is adjacent to the powerhouse. The upstream foundation walls of the powerhouse have been calculated so as to withstand the water pressure resulting from a penstock burst.

The Bia plant operates in parallel with the Francqui station, with which it is connected by a 120,000 V line. The supply system and the tailrace structures are designed to cope with the maximum discharge from the Francqui plant, and each of the Bia turbines can pass the discharge of two of the Francqui units.

Lualaba Development

The hydro-electric development of the Lualaba River was dictated by the increasing power requirements resulting from the commissioning of new copper works which, because of their distance from the Lufira plants (about 200 km.) could not be supplied from either Francqui or Bia. The Lualaba rapids were the obvious choice as a development site, since they are no more than some twenty kilometres away from the western group of mines.

The Lualaba has its source on the Rhodesian border at an elevation of 1,345 m., i.e. 1,000 m. higher than its confluence with the Lufira, 600 km. further downstream. Two hundred km. from the source, the Lualaba enters the N'Zilo gorges, dropping from 1,220 to 775 m. over a stretch of 64 km. This narrow and winding valley, abundant in rapids and small waterfalls, lends itself particularly well to multi-stage development. The catchment of the Lualaba has an area of 16,300 sq. km. and has similar characteristics to the neighbouring Lufira basin. The low-water discharge is 30 cu. m. per sec. and the maximum flood discharge 600 to 700 cu. m. per sec., while the mean run-off coefficient is 0·166 and the average flow 104 cu. m. per sec.

The upstream end of the N'Zilo gorges appeared particularly favourable to the construction of a high dam which would create a storage reservoir large enough to regulate the flow of the whole river. It was therefore decided to initiate the Lualaba development at its uppermost stage. Survey work began towards the middle of 1948 and construction followed immediately, the first of the four 38,000 h.p. units being put into operation in December, 1952, less than five years after the beginning of the first field surveys. This, the first stage, operates on a maximum gross head of 83 m., which decreases to 66 m. when the storage reservoir is empty. The Delcommune scheme, as it is called, has involved the construction of a thin arched concrete dam, without reinforcement, 72·5 m. high and 162 m. long at the crest, having a maximum thickness of 13 m. at the base, and 3 m. at the top. In addition to a 2·5 × 3·0 m. bottom outlet, controlled by a downstream regulation gate and an upstream stop gate, this structure is provided with a flood control spillway on the left bank, consisting of two sector gates 9·0 m. wide and 6·6 m. high. The intake is provided with two cofferdam gates 3·5 by 6·0 m. and a fine trashrack having a gross area of 120 sq. m. fitted with a mechanical rake. This structure, 30 m. high is designed for a discharge rate of 150 cu. m. per sec. and is situated to enable the

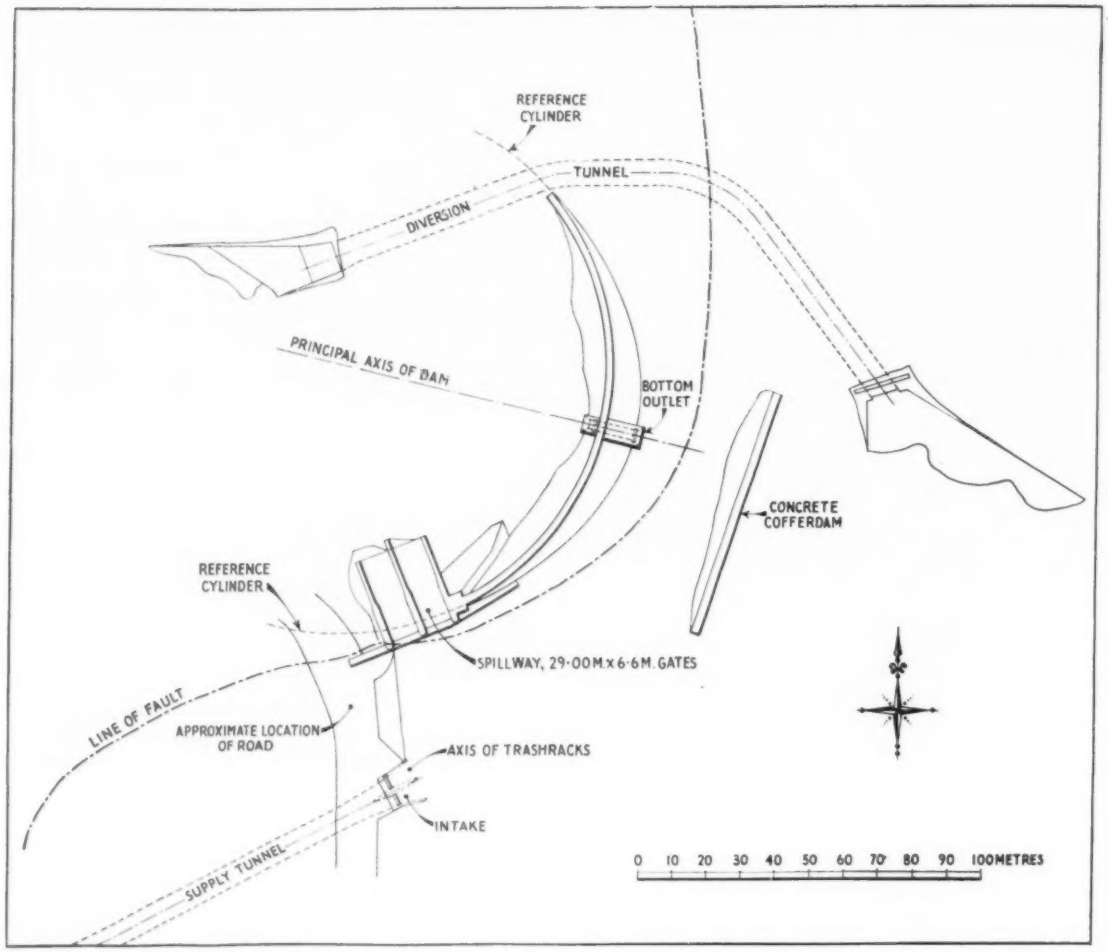

Fig. 11. Layout of Delcommune dam, intake and diversion tunnel

storage level to be lowered by 17 m. The pressure supply tunnel, 42 sq. m. in useful cross-section and 1,800 m. in length, is concrete lined throughout.

A 19·5 m. dia. surge chamber is provided with an expansion chamber 31·5 m. in dia. at the top, and a bottom constriction 3·6 m. in diameter. There are two rock tunnels, steel lined, 90 m. in length by 4·5 m. in dia., and each connecting downstream with a two-branch manifold 2·95 m. in dia. From these manifolds four 106·5 m. long steel penstocks are taken to the power-station, which houses four vertical-axle Francis turbines, each developing 38,000 h.p. and driving a 30,000 kVA alternator at 333·3 revs. per min. This building stands on the left bank of the Lualaba, the turbines discharging directly into the river without an intermediate tailrace. Upstream of the powerhouse is the outdoor 6,600/120,000 V transformer station, erected in the same longitudinal axis.

An interesting feature of the dam of the Delcommune plant is that it is built on a site where the general slope of the right bank of the valley is 58° and only 47° on the left bank. To obtain a symmetrical structure, an abutment was set up on the left bank, but all calculations were worked out as for an asymmetrical structure, earth tremors characterised by an acceleration of 0·1 *g* being taken into account. The whole structure rests on both banks on quartz rock which, although fractured, is of sound quality.

All four generating units have independent sets of foundation and, as at Francqui and Bia, the turbines rest on the concrete blocks which house the draught tubes. This type of foundation enables each unit to be erected without having to wait for the foundations of the remaining units to be completed.

The Le Marinel Power Station, which has been in course of construction since April 1953, constitutes the second stage of the Lualaba development, its purpose being to utilise a 46 km length of the upper end of the N'Zilo gorges. This stretch includes the Lukuka jump, some 30 m. high, followed by a stretch of rapids which increase the natural difference in level to about 50 m. over a length of 360 m. The surveys undertaken in 1951 immediately upstream of the waterfall failed to reveal any site topographically and geologically suitable to the erection of a dam 100 m. in height as was desired. The search for a more favourable site was therefore moved upstream, although it was

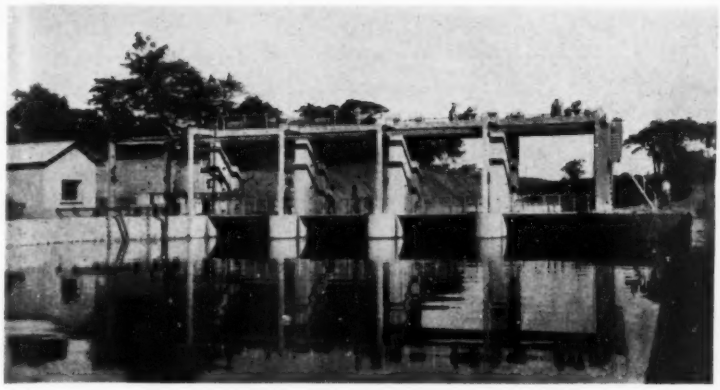

Fig. 12. Intake works, Bia plant, at Koni

realised that a considerably longer supply tunnel would have to be provided. It was at this juncture that investigations turned to the possibility of returning the turbine discharge not direct to the Lualaba below the Lukuka fall, but to the Seke, a small tributary of the Lufupa River which is itself an affluent of the Lualaba. The upper Seke follows a course fairly parallel to the Lualaba, but a few kilometres away, and presents the very interesting peculiarity of a level some thirty metres or so below the Lualaba at the site first contemplated for the return of the power-house discharge. The Le Marinel project envisages a rock-fill dam 70 m. in height, 210 m. in length at the crest, and 805,000 cu. m. in aggregate volume, with an upstream water-tight core of argillaceous or bituminous material. This dam will have an emptying tunnel independent of the diversion tunnel necessary for its construction, and a flood-control spillway designed for a discharge of 1,000 cu. m. per sec. The artificial lake, 65 million cu. m. in capacity and 3·34 sq. km. in area at the maximum storage level, will act purely as a storage reservoir, since the flow of the river is fully regulated by the reservoir of the Delcommune plant; its level may however be subjected to slight daily fluctuations. The water supply will be drawn off by a pressure tunnel, 2·5 km. in length, 42 sq. m. in cross-section, and equipped with a surface intake and a surge chamber. Two steel-lined tunnels and four penstocks will feed the 89,000 h.p. vertical-shaft turbines coupled to 69,000 kVA alternator units. An

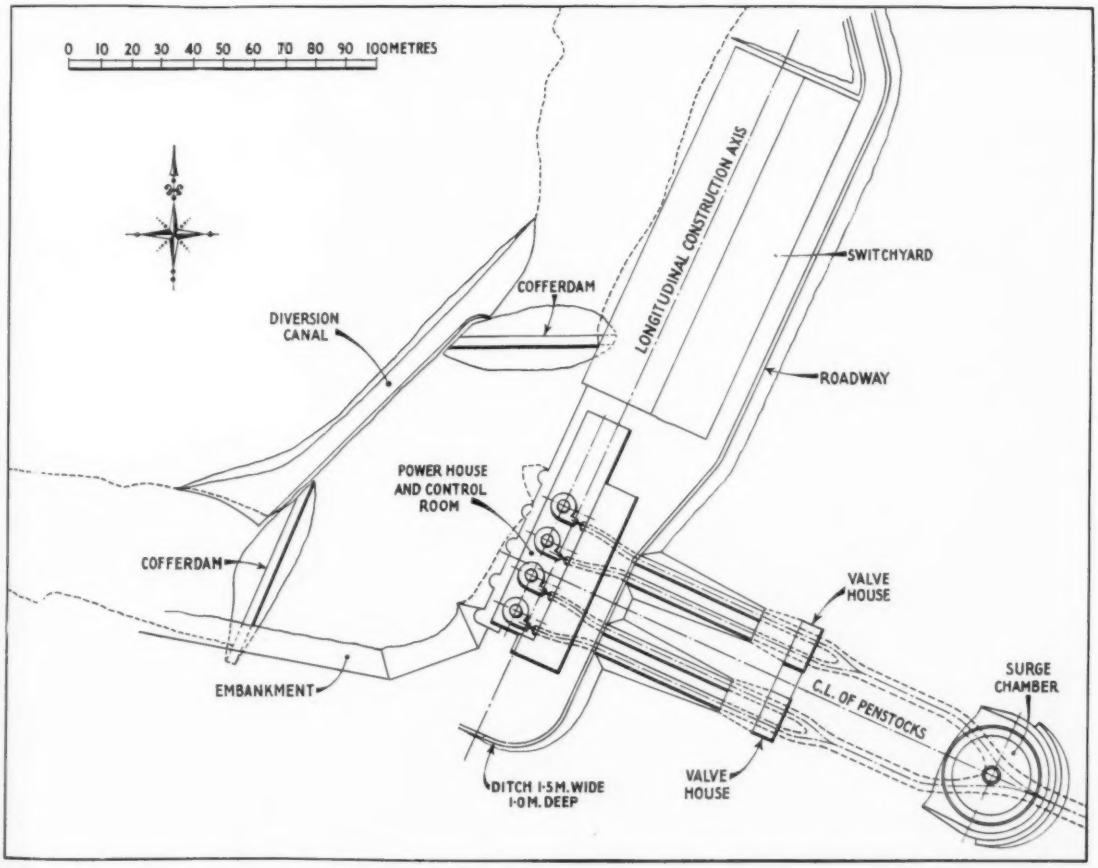

Fig. 13. Layout of Delcommune power station and associated works

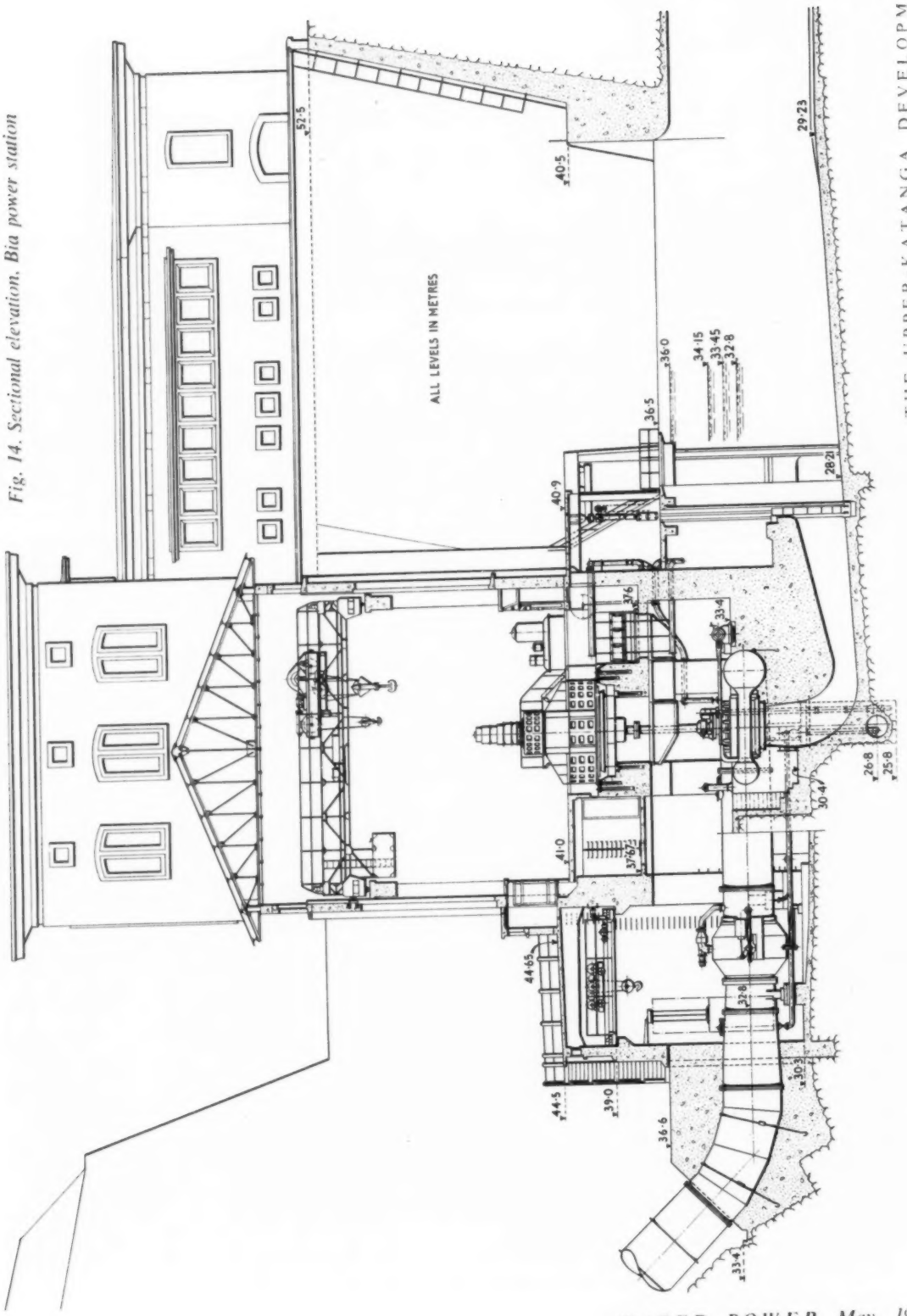

Fig. 14. Sectional elevation, Bia power station

Fig. 15. Dam and resulting lake, Bia scheme, Koni

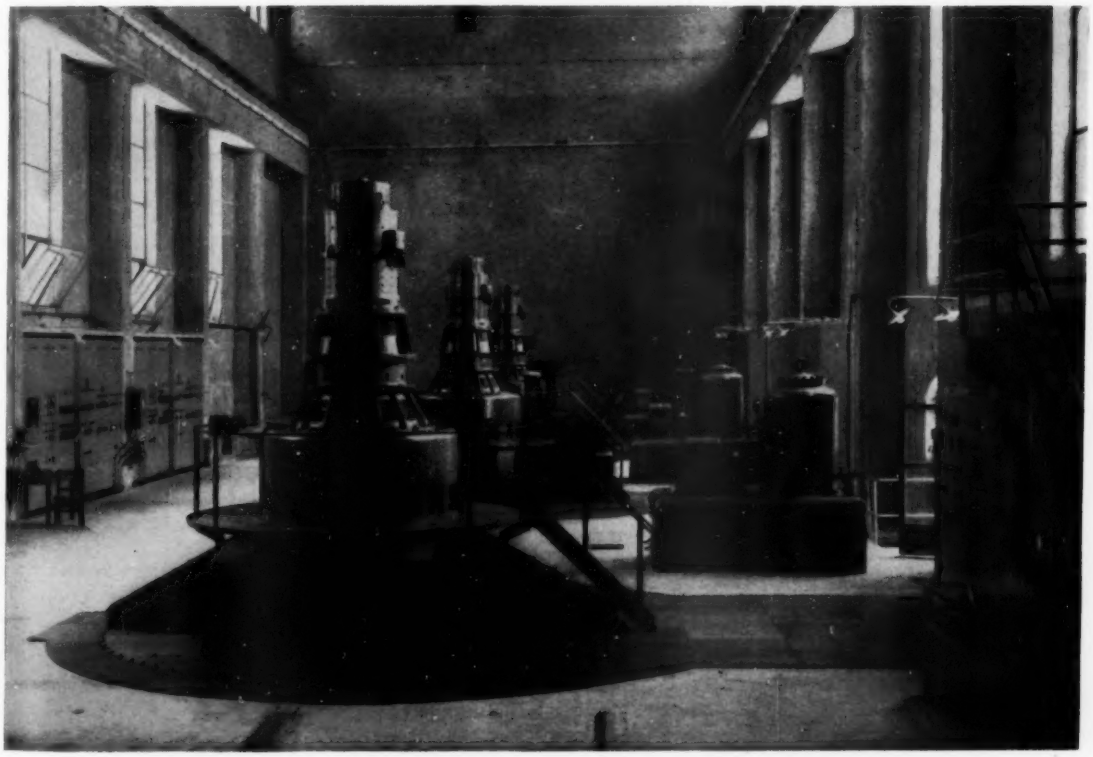

Fig. 16. Interior of Bia powerhouse showing the three generator sets

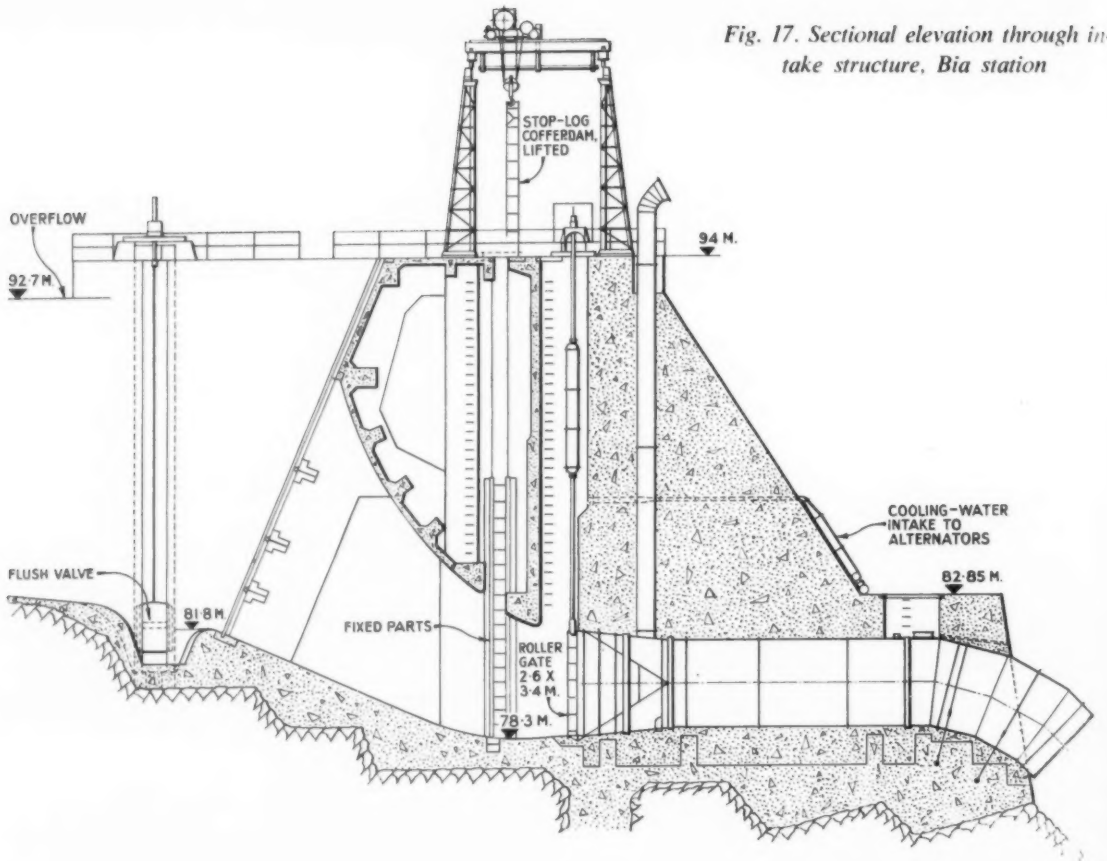

Fig. 17. Sectional elevation through intake structure, Bia station

open tailrace canal 1·5 km. in length is to be excavated in the bed of the Seke, so as to gain another 20 m. of head. Owing to this layout, the powerhouse will be built at the bottom of a deep excavation.

A 10,500/220,000 V transformer station, adjacent to the powerhouse, will be provided, and it is expected that in an average year the Le Marinel plant will be able to supply 1,130 million kWh to the consuming centres by means of a 400 km. transmission line. The first generating unit is scheduled for commissioning towards the end of 1956.

The Haut-Katanga Reservoirs and their Problems

In addition to general operating factors, more or less common to all hydro-electric schemes, the utilisation of the storage lakes of the Haut-Katanga for power generating purposes confront the U.M.H.K. with two particularly awkward problems, viz. aquatic vegetation and evaporation losses.

There is no direct preventative for evaporation, which plays such a considerable part in the operation of large-area reservoirs, especially when situated in intertropical regions such as the Katanga. A knowledge of the extent of evaporation loss is, however, of the utmost importance and model tests, carried out before the level of the Francqui reservoir was raised —extending its area to 450 sq. km.—have shown that the value of annual evaporation fluctuates around 1,500 mm.; this means, referred to the Francqui and Delcommune reservoirs, a yearly loss of 450 and 240 million cu. m. respectively; or, expressed in terms of supply to the turbines, 14·3 cu. m. per sec. and 7·6 cu. m. per sec.

In comparison with evaporation, aquatic vegetation is very much the lesser evil. Not only does it cause smaller losses in power water, but it is also possible to keep it under control to some extent, though the problem is still awaiting its final solution. As first observed in the reservoir of the Cornet falls a few years after it had been impounded, weeds begin to grow along the banks and to form islets which rapidly expanded in area and subsequently become so thick and compact that the native fishermen in quest of a catch tread on them as unconcernedly as on firm ground. Unfortunately, the wide fluctuations of the water level cause large areas, which have become thoroughly drained towards the end of the dry season, to be once more inundated at the end of the rainy period, and there are also shallow zones over-run with weeds. The submerged weeds rise subsequently to the surface and form vast floating beds of up to several metres in depth. Unfortunately the winds predominating in this region blow these beds towards the Francqui plant, where they drift towards the intake works. In years of mean or abundant rainfall, areas of as much as 100 hectares are covered by these floating beds. The main problem was, of course, to prevent

(Continued on page 188)

New Plant Inaugurated in Brazil

The Itutinga power plant owned by the Companhia de Eletricidade do Alto Rio Grande (CEARG), and of which we gave some account in our January, 1954 issue, was inaugurated recently by Governor Juscelino Kubitschek. This plant, it will be recalled, lies in the centre of an area rich in iron, manganese and uranium deposits and is situated some 120 miles south of the city of Belo Horizonte. The power generated will thus find its main outlet in this important mining field.

The project was begun early in 1952 and progress has been very satisfactory. Our view was taken a few days before the dedication date and shows one of the units already complete and the second in course of erection. Each generating unit is of 12,000 kW capacity and is operated by a kaplan turbine working under a head of 29·5 metres and having a speed of 225 revs. per min. All the units will be of the outdoor-type, as will be obvious from the aerial view.

The plant will be completed in stages and it is not proposed to build more than two units for the time being. Provision has been made for two further units to be added, however, as the load expands and as the upstream regulation is made more complete. The ultimate capacity will be 48,000 kW and this power will not only play an important part in the development of the mineral field but will also be used to provide a public supply to the towns of Lavras, São João del Rei and Barbacena.

The scheme was entrusted to The International Engineering Company of San Francisco and the turbines and valves were supplied by S. Morgan Smith and Company. All the electrical equipment, together with the step-up substation, was supplied by the Westinghouse Electric International Company.

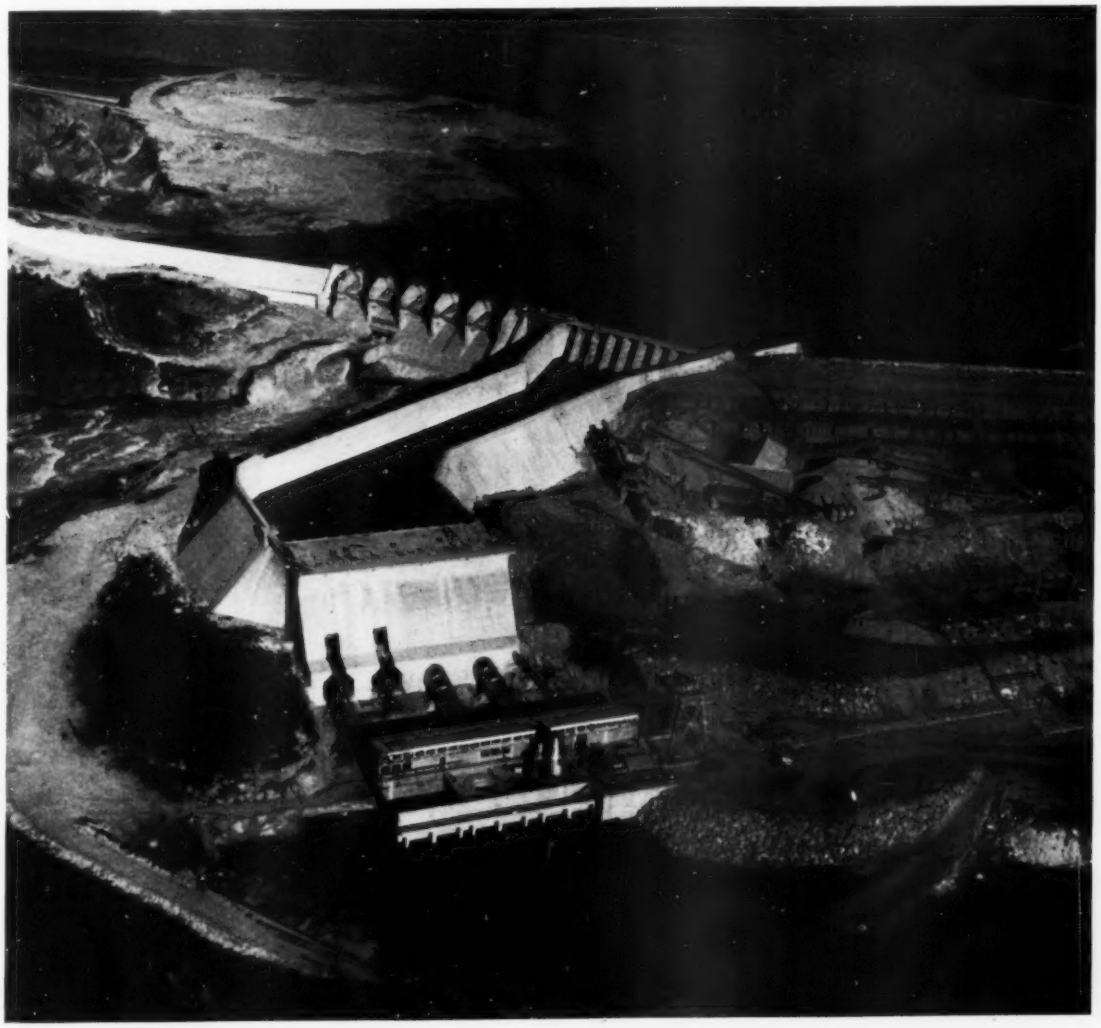

Fig. 1. Aussois; a modern high-head, high-power penstock having an internal diameter of 1·6 m. and plate thickness in the lower sections of 16 mm. The maximum head is 1,000 m. and the total power developed is 130,000 h.p. The pipes are self hooped (Ferrand system) with laminated hoops, the maximum section being 80 × 46 mm. This penstock is protected by a bituminous varnish with an aluminium finishing coat

Protection of Penstocks against Corrosion

This article represents the substance of a lecture given by Robert Bouchayer* to l'Association des Ingenieurs en Anti-Corrosion.

IT is very difficult to form an idea of the losses annually sustained on account of the corrosion of penstocks. Penstocks are usually buried in virgin soil, in mountainous country, and in cases where the water contains lime some of them have functioned for very many years without suffering appreciable attack on either the exterior or the interior surface. On the other hand, in the Massif Central for instance, extremely rapid corrosion in the interior of penstocks has been observed, so that it is difficult to give a conspectus of the problem.

In any case, penstocks installed nowadays are much thinner, due to technical advances, and a similar degree of wear may be much more dangerous than formerly, so that both manufacturers and plant owners have become convinced of the necessity to protect the interior effectively as well as the exterior.

It is not the author's intention to develop a theory of protection or to discuss the advantages and disadvantages of one or other method of protection, but to draw practical conclusions from observations he has made in recent years. It is therefore proposed to describe the conditions to which coatings are subjected and to try to define the requirements for making and erecting a penstock with a view to clarifying the problem itself.

The penstocks serving hydro-electric stations operate generally under high pressure. Their diameters range from 700-800 mm. to 5-6 m., and the power conveyed from a few thousand horsepower to 200,000 h.p. Heads in some cases exceed 3,000 ft., requiring the installation of rope railways or aerial ropeways to raise each section (weighing up to 15 tons) to the position where it is welded to the preceding section. Once erection is completed, these constructional installations are usually dismantled, and it then becomes extremely difficult to reach either the inside or the outside of the penstock.

The Corrosion Problem

The factors involved in the problem of corrosion may now be set out as follows:—

1. Work on penstock erection proceeds during all seasons, and one cannot tell in advance whether erection will be completed, and thus the proper moment for painting arrive, during good or bad weather.

2. The surfaces to be covered are considerable, of the order of several thousand square feet and in some cases of several tens of thousands. Several coats have to be applied, and the time required for the work will, for the most part, exceed the intervals of good weather that can be reasonably expected between May and October.

3. Penstock profiles are often steep and indifferently served by a ropeway, and painting must be done immediately erection is completed if advantage is to be taken of the constructional installation.

4. For the reasons already given, maintenance is extremely inconvenient, and it is always very difficult to get painters and protective materials to do the job.

5. As soon as a penstock has been completed and is placed under pressure, not only is the inside surface wetted but also the outside, due to condensation. The protection of a penstock against corrosion must be directed particularly to resisting the action of water.

6. The penstock may need to be emptied in due

Fig. 2. Pouget penstock, 2·7 m. diameter, 530 m. maximum head and carrying 160,000 h.p. The pipes are self hooped with flexible hoops, the maximum plate thickness being 22 mm. and the hoops being formed of steel cable wiredrawn at 200 kg. per sq. mm. The entire pipe protection was applied at the works, the only work done on site being to complete the protection of the welded joints. The elbow, which is anchored in concrete, is protected by a limewash only. After erection the complete penstock received a general wear resisting coat

* Joint Director-General, Société Dauphinoise d'Etudes et de Montages, Ets Bouchayer et Viallet, Grenoble.

course, and at such a time the range of temperature variation will be considerable (80°C between summer and winter and 30-40°C between day and night).

Traditional Methods of Protection

Before drawing practical conclusions from the foregoing six observations, we must say a word about traditional methods of protection which have been in use for 60 to 80 years.

Exposed penstocks are known to rust by reason of the following:—

1. Damage to paint by falls of stone, by soil marks, etc.
2. Peeling of the mill scale.
3. Poor quality of application; sweating of the pipes during painting.
4. Leakages from riveted or bolted joints.

In the case of a penstock laid in a tunnel, the fall of drops of water from the roof on to particular portions of the penstock may add a local effect to that of the general humidity.

Information about buried penstocks is inconclusive. The author knows of a penstock 3 mm. thick which has remained in service for some 50 years, whereas another, 6 mm. thick, installed in 1923, was corroded through at several points 15 years later. Some other penstocks were corroded even more rapidly by the action of stray electric currents.

Fig. 3. Interior of a length of penstock pipe showing ability of a hot-applied enamel to withstand damage due to an accident in transport. The roughness of the enamel, which is applied to a thickness of 1 or 2 mm., disappears very rapidly under the influence of water flow and once smoothed this form of protection offers a lower roughness coefficient than any other type of coating

For most exposed penstocks it has been the normal practice to protect them with two coats of red lead followed by one or two coats of oil paint. These coatings must be regularly renewed on account of the permanent moisture which finally destroys them.

Some exposed penstocks and practically all buried penstocks are coated with tar, and more recently with bituminous varnish. These bituminous coatings have generally given satisfaction in very wet tunnels, but have been found unsatisfactory for penstocks exposed to direct sunlight.

Buried penstocks are usually wrapped with jute and protected by a thick coating of tar. Penstocks embedded in concrete are covered with cement slurry and concreted directly in place without a coating.

On the inside of a penstock rust arises from:—

1. The chemical composition of the water.
2. The peeling of mill scale.
3. Differences in the quality of the steel plates.
4. Defective and porous coatings.
5. Erosion.

Lime deposits, 2-10 mm. thick, are often met with, and although these incrustations may have a protective action, they can give rise to an appreciable loss of head. In Switzerland measurements on a high-head penstock have disclosed an increase in head loss of 3-4 per cent., in other words, the loss has been doubled after a few years' service.

A fairly large number of penstocks have been protected on the inside by one or more coatings of red lead. Where the red lead has been free from incrustations the protection has been complete, but in other cases the red lead has totally disappeared, never to be replaced.

Other penstocks are protected on the inside by bitumen or tar in fairly thick layers applied cold or hot.

Finally, mixed coatings have been applied—red lead for undercoats and bituminous coatings for finishing.

These protective coatings were applied partly in the works and partly on site. Between 1940 and 1947 most applications were effected on site, for, on account of the difficulty of obtaining protective media, the manufacturers virtually left it to the care of the consulting engineer to arrange directly with a supplier or subcontractor.

Recommended Methods of Protection

The first factor noted above, under "The Corrosion Problem," is the uncertainty as to the time of year in which erection will be completed, and this uncertainty weighs heavily against the possibility of achieving perfect quality in the protective coating. It is practically unthinkable to leave a squad of painters on site for many weeks during periods of bad weather to profit by the few hours a day or the few days a month during which painting may be possible.

The second factor, that of the extent of the surfaces to be covered, strengthens the suggestion that even if erection is completed at a favourable time of year, painting on site requires appreciable time, and it would be necessary to organise the work so that the painters do not hesitate to suspend work during rain or when the penstock is covered with dew.

In view of these difficulties, which we have encountered to our cost—and the author has in mind particularly the installation at Passy, where the

painters returned three or four times without being able to finish their work completely—we decided to carry out the major part of the protective work, if not the whole of it, at the works. To begin with, we believe this is wise from the standpoint of quality, for operations at the works are necessarily carried out on dry surfaces. Secondly, co-ordination of the work is facilitated, and when erection is reported as complete there is nothing to prevent the penstock being filled. Finally, the consuling engineer will find in this a source of economy because work in the factory is less expensive than work on site.

Regarding the third factor, application at the works is a welcome solution to the difficulties of application on site where the profile is steep, such as in the case at Pragnères, for instance. At Pragnères, however, most of the protection was applied on site for two reasons: first because the constructor's works at that time did not have the capacity to apply three coats of paint on some 40,000 sq. m. of penstock, and secondly because all concrete was carried up the track by ropeway and the penstocks had to be cleaned of cement droppings from the ropeway skips. Finally, in view of the importance of the Pragnères installation, the ropeway was made permanent, and it is therefore possible to work on the profile.

Nevertheless, if the constructor had this work to do again he would apply all the protection at the works, and would arrange with Electricité de France to apply, after erection, a supplementary coat which he would call an "indicator coat." In fact, after cleaning away traces of concrete we should have painted on a coat of a different colour from that applied in the works, and which would have been renewed regularly so as to preserve intact the protection given in the works.

This technique has a supplementary advantage. The delay in erecting such a penstock is such that the application of a single coat at the works would not be a paying proposition. Most of the pipes, in fact, are subjected to the extremes of summer and winter before receiving their final protection, and as everyone knows, if a single coat lasts a year, two coats will last much longer and three coats will last twice as long again. For contracts that extend over many months it is therefore as logical to apply the final protection at the works as it is to apply it on site.

The fourth factor—that whatever the protection it must be extremely durable—also confirms our thesis of application at the works, for to obtain durable protection it is absolutely necessary to prepare the surfaces perfectly. This is obtained by sandblasting or shotblasting followed immediately by a first anti-rusting coating. Such an operation can only be carried out with complete certainty in the works. For this reason we have installed at our Grenoble works a shotblasting cubicle provided with all modern refinements to enable surfaces to be prepared perfectly for painting, stove enamelling, or metallisation.

The fifth factor led us to investigate what kind of coating was most resistant to moisture and rust. We conducted laboratory tests to discover, on the one hand, products that could be applied to moist surfaces for use on site, and on the other hand, what products best resisted disintegration. In the second series of tests we studied simultaneously the behaviour of the following protective media: (1) three coats of bituminous solution; (2) bituminous enamel applied hot; (3) undercoat of red lead and finishing coat of bituminous paint; (4) glyceryl phthalate undercoat and bituminous glyceryl phthalate finishing coat; (5) red lead undercoat, finishing coat of oil paint; (6) bituminous protection with aluminium finish.

Fig. 4. When the penstock dimensions are such that protection cannot be applied at the works, the pipes must be scaled and painted on site

The six test plates were weighed before being subjected to the following:—

(a) At predetermined intervals they were immersed in, or withdrawn from, a bath adjusted to a Ph value of 6 by the addition of a trace of phosphoric acid. A clockwork mechanism immersed or withdrew the specimen every half hour, and the plates were weighed every week.

(b) After 28 days they were subjected to an accelerated ageing test comprising three cycles daily for a month, each cycle consisting of: (1) half an hour in running water; (2) half an hour freezing to $-15°C$; (3) quarter of an hour warming to ambient temperature; (4) half an hour in steam; (5) half an hour in sulphurous vapour; (6) an hour at $60°C$ under ultraviolet rays.

(c) After 50 cycles the test specimens were once again subjected to immersion and withdrawal for several weeks. After 500 cycles the following results were observed:—

Aluminium Protection. Aluminium forms an anode and results are excellent so long as any aluminium remains. After 21 cycles the aluminium is no longer adherent and the loss of weight is considerable. Nevertheless accelerated ageing has the unforeseen effect of refixing the aluminium, which resists a further 20 cycles. We have concluded from these tests that aluminium protection is excellent as an "indicator coat" and that to obtain satisfactory results the thickness of the coat must be above a certain minimum. For penstocks that can be repainted with aluminium we recommend the application of two or three coats of aluminium paint on site, in addition to the protection applied in the works, and that this coating should be periodically renewed. We have used

this technique for the Afourer penstocks in Morocco, for which the pipes were covered at the works with two coats of black bituminous solution followed by a coat containing a proportion of aluminium. As erection proceeded, a new coat of aluminium was applied, which had the advantage of considerably reducing the heating of the plates. Finally, after erection had been completed, the three penstocks were given a finishing coat which gave them an absolutely faultless appearance.

Oil Paints. Protection by oil, whether by red lead and anti-rusting oil paint, or red lead and bituminous oil paint, proved to be the worst of the series. The variations in weight were considerable, and on the mixed test plate (red lead plus bituminous coating) a network of cracks developed to a significant extent although the red lead coating had been given its proper time to dry.

This is not to say that these forms of protection are not good, for in these tests they withstood pretty severe conditions satisfactorily, but the results were not so good as those obtained with test plates protected by glyceryl phthlate or bituminous coatings.

Glyceryl Phthalate and Bituminous Coatings. These two methods of protection gave absolutely perfect results, both in the destruction and in the accelerated ageing tests.

We have come to the conclusion that these media should be used in preference to all others, particularly as they possess the additional valuable quality of rapid drying. Bituminous solutions dry in three days and glyceryl phthalate in a few hours. In this connection it would not be practicable for us to organise our production on a basis of red-lead protection, for our works despatch from 400-500 tons of pipes per month, and red-lead protection would call for permanent stocking capacity to accommodate 500-1,000 tons.

Hot Bituminous Coatings. Thick bituminous coatings applied hot naturally gave excellent results in the destruction tests but they were not so successful with respect to accelerated ageing, in which ultra-violet rays were found to exercise a predominating influence.

General Conclusions

On the assumption that in all cases the surface to be protected is cleaned by shotblasting, our recommendations are as follows:—

For Penstock Interiors the application of hot bituminous enamel. This possesses the advantage of wearing absolutely smooth under the influence of the water flow, of reducing the head loss, of resisting the formation of incrustations particularly well, of being equally resistant to abrasion, for the shape of the bitumen molecule tends to least resistance, and finally, on account of its thickness, of presenting an excellent guarantee of long life. We have used these enamel coatings on a fairly large number of installations, and we can confirm that they are not only conducive to a better quality of application but they withstand transport perfectly. On site it only remains to protect the welded joints.

Although we have staff qualified to apply these protective coatings on site, we prefer to engage specialist firms so that they can give their guarantee conjointly with ours. As soon as the pipework has been received on site, protection is arranged by a joint meeting between the consulting engineer, the enamel supplier, the painter, and the contractor.

We have experimented with the application of hot enamel by spray gun, but we have not definitely adopted this technique because it is subject to three objections:—

(a) Projection from a spray gun cannot be effected without the formation of tiny bubbles, which conceal the work and are the cause of defects and even of porosity.

(b) Vaporisation at the spray-gun nozzle may vary the composition of the product applied to the plate, and the coating is not so homogeneous as that obtained by brush.

(c) A spray gun necessitates the adoption of petroleum-based enamel. The use of such enamel is nowadays subject to criticism.

Nevertheless, we used this method for protecting the interior of the Pouget penstock, where we observed these defects and had to supplement the protection by a galvanic method. We placed a number of magnesium anodes inside the penstock to eliminate all danger of pinholes in places where porosity in the coating was apparent. This method is in course of observation, and it is too early to draw conclusions of use for other installations. When these conclusions are known they will be of great value because the water at Pouget is particularly corrosive. After the installation had been in service for some months an inspection of the penstock revealed serious corrosion at certain places which had not been protected by enamel. The following year, after the magnesium anodes had been placed in position, the corrosion seemed to have practically ceased.

For External Protection we recommend the use of hot bituminous enamel for penstocks to be buried or placed in tunnels. For buried penstocks we always apply the enamel in the works. We apply a first coat to a thickness of about a millimetre. Then we wrap the whole surface with strips of glass fibre woven in a wide mesh (5 × 5 mm.), before applying a second 1 mm. coat of hot enamel. The width of the mesh allows of a perfect bond between the two coatings, such that the glass fibre is embedded in a homogeneous thickness of bitumen. The mechanical resistance of the bitumen is considerably enhanced, and the coating can withstand hammer blows or falls of stones or earth when being buried.

In the case of self-hooped pipes the glass fibre cannot be incorporated in the enamel, and the enamelling operation is carried out on site. In view of the difficulty of applying hot enamel on site, products suitable for cold application in considerable thicknesses are employed.

For the Exterior Protection of Exposed Penstocks we differentiate between three cases:—

(a) Where the penstock will be subjected to wide temperature variations we always recommend a finishing coat of light colour. Aluminium is not always accepted by the authorities concerned, and recourse has to be made to oil paints. In such cases we advise the application in the works of an anti-corrosive coating having an iron-oxide or zinc-chromate base, followed by a coat of dark oil paint. On site the protection is completed by a lighter oil paint which constitutes the "indicator coat."

(b) Where aluminium finish is acceptable, we recommend the application of a black bituminous solution in the works, and of a bituminous aluminium

Fig. 5. Cap de Long penstock, Pragnères; the steep gradient has necessitated the use of powerful ropeways

solution both at the works and on site, as explained above.

(c) Where the penstocks will not be subjected to wide temperature variations, such as the case of Malgovert, where the penstocks face north and pass through a wood which protects them from the sun, we recommend the use of best-quality bituminous solutions.

In all these cases we attach very great importance to the brand of the product. We do not doubt that the great majority of paint manufacturers supply first-quality products, but we consider that a factory of small capacity is necessarily without the requisite research and control organisations. We therefore seek to use products for which there is a large demand, and which are supplied regularly by powerful organisations possessing well-equipped laboratories and having services which guarantee the regularity of delivery.

On their part, such suppliers do not hesitate to replace substantial consignments if any doubt arises as to the quality of the delivery or if their laboratories have introduced further improvements in quality between the date of the order and the time when the product is used. The references we furnish, in effect, are of the first order, and the paint manufacturers do the impossible so that these references may be to their credit.

Guarantees

The technique of penstock protection that has just been described has been established as the result of factual observations, and consequently offers a certain guarantee. Nevertheless it is not in this sense that the term is generally understood, and the consulting engineer nowadays requires us to guarantee by contract the durability of a protective covering against corrosion. Indeed, certain contractors, in order to obtain a contract, do not hesitate to give guarantees of long life and to cover themselves by an insurance policy against the risk of deterioration of the structure. As things are we prefer to refuse to give such guarantees, for we are technicians and not an insurance company, and we do not wish to mix commercial arguments with a theory based solely on technical considerations.

To obtain the best life for a protective covering, it is, in our view, necessary to apply the largest possible number of coats. Where a thick bituminous covering is concerned the life is 20 to 30 years or more, as our records abundantly testify. (Naturally the quality of the products and of their application must be perfect.) As regards thin coatings, the life depends on maintenance. Speaking subject to correction, the Eiffel Tower is repainted with the utmost regularity, and the original red-lead coating is still intact. In our opinion it is a disservice to the client to give him a guarantee for, say, ten years, for this means that for ten years no maintenance work will be carried out. After the ten years it is probable that the protective covering will have to be renewed in its entirety and this will be much more expensive than if a minimum of maintenance had been carried out from the fourth or fifth year.

We therefore give a full guarantee for a year, that is to say, for a period sufficient for the penstock to be subjected to summer and winter conditions. Any fault in materials or in their application cannot fail to be revealed by the end of a year. Thus, when the job is handed over, the consulting engineer will be in a position to know, without fear of implicating himself, whether the protection has been applied in accordance with the best practice and will give him satisfaction, or whether it should be regarded with caution. After the year's guarantee has expired, we ask our clients to take over the maintenance of the penstock, and our unconditional guarantee lapses. We specifically retain the ten-year guarantee appropriate to the work of the manufacturer and contractor. In fact, this means that our guarantee is unconditional for a year, and extends to ten years against all hidden defects—which is exactly in line with the practice of our competitors—but we do not guarantee against normal wear and tear or fortuitous damage. Any other basis seems illusory.

Metallisation

Up to the moment we have used metallisation for the protection of structural steelwork in power

stations but we have never used it for the protection of penstocks. That is not to say that metallisation may not be a valuable process, but so far we have had too much to do in contending with conservative ideas which revolve themselves primarily into considerations of price, to be able to convince our clients that the expense of metallisation may be worth while. The cost of the protection of a penstock is always a tiny fraction of its total cost, but it is always regarded as too much. Even in the case of very high-power installations such as Malgovert, Pragnères or Pouget, the consulting engineer has been hard put to it to allocate substantial sums to penstock protection. For smaller penstocks the protection is always treated as a "poor relation," and as the consulting engineer only takes into account the total cost of the installation one is tempted to reduce the cost of painting to the minimum to avoid the risk of losing the contract.

In these circumstances there can be no question of considering the use of expensive protective media even though they may rapidly recover their cost. The plastic industry today offers new anti-corrosion possibilities. In our laboratory we are investigating various products and certain impermeable fabrics, but it is too early to draw any conclusions.

Conclusions

The protection of penstocks is secured mainly by bituminous products, and this by reason of their perfect resistance to the action of water. The ideal procedure, after descaling, would appear to be to impregnate the surface with a quick-drying anti-corrosive product, and then to apply impermeable bituminous media. We have made tests, but up to the moment they have not been fully satisfactory, and we are keeping to homogeneous protection—three bituminous coats. We employ anti-rust paints only when aesthetic considerations prevent the use of black or aluminium.

Finally, we are convinved that it is better to apply the protective coatings in the factory. These are the two main conclusions of this treatise.

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the weeds from entering the intake; the first appliance used for this purpose consisted of panels of coarse trashrack fitted into the stoplog grooves of the four intake gates, and in addition, a 300 m. long floating screen inserted between the flood gates and the intake. One after the other, the weed beds are driven—occasionally with the help of winches—towards one of the 10 × 4 m. flood gates, through which they are swept along by the water. One gate only is used at a time in order to prevent the weeds from getting stuck against the gate piers. In spite of great water losses and heavy labour costs, this method was accepted as being a satisfactory solution of the weed problem at the Francqui plant. When the Bia installation was put into service in 1949, however, and the same method applied, it was soon discovered that the evacuated weed beds, torn to pieces by a drop of over 100 metres, were taking root again in the lower Bia reservoir, covering it with a huge green carpet, especially at shallow spots upstream and along the banks. In this instance the floating screen has not proved quite adequate and investigations are now in progress with a view to stopping the weeds removed from the upper storage from reaching the lower reservoir. A barrier of old rails fixed in the rock bed of the river has failed to produce satisfactory results. It is also contemplated to block the Mwadingusha reservoir by means of a floating trashrack fitted across a 300 to 400 m. wide channel, a few kilometres upstream of the dam, and then to haul the weeds to the banks and burn them. Other solutions under consideration are: destruction of the weeds by chemicals, clearing by means of long-handled scythes, and splitting the beds by blasting. The magnitude of the whole problem rules out an easy solution, but it is expected that floating trashracks will prove efficient at the Delcommune and Le Marinel plants, where, owing to the greater depth of the Lualaba reservoirs, the weeds do not spread to the same extent as in the Lufira lake.

Pending a satisfactory solution of the weed problem, the U.M.H.K. is planning to reduce evaporation and transmission losses as much as possible by closely co-ordinating the operation of the two groups of power stations. The Lufira plants are called to play the major part in this co-ordination, and it appears from preliminary investigations that an optimum utilisation of their output will permit a yearly economy of 4 million kWh to be achieved in transmission losses, and no less than 56 million kWh in evaporation losses. Once the Le Marinel plant is ready, the U.M.H.K., in co-operation with the Société de Traction and Electricité in Brussels, will have reached the completion of a major stage in the electrification of the Haut-Katanga. The scope of this development is best illustrated by the fact that its production of 2,000 million kWh will be equal to half the total production of electric energy in Belgium.

Sir Lindsay Parkinson & Co. Ltd. have published a handsomely produced book entitled "This Way Forward", which gives an illustrated record of the firm's activities during the last 75 years. In this period they have erected many notable buildings including bridges, power stations, hotels and other structures such as deep-water quays, piers and dams. The book has an interesting story to tell and although no emphasis is placed on the historical aspects of the firm's endeavours, the scope of the work undertaken, its variety, and the obstacles overcome give a fine contribution to the far larger story of industry's changing methods and the more exciting things that are yet to come. It will be recalled that the firm has now started work on the new port of Tema in the Gold Coast. This port is necessary to the economy of the Gold Coast whether the Volta River aluminium scheme goes forward or not, but its importance will doubtless be enhanced if, as is to be hoped, the scheme is brought into being.

The Butterley Co. Ltd. have changed their London address from Ashley Place to 9 Upper Belgrave Street, S.W.1. Tel. Sloane 8172 and 9106. Telegrams and Cables—Butterley Sowest London.

Jenolite Limited, a firm which specialises in corrosion problems, have moved their offices from Piazza Chambers, Covent Garden, W.C.2., to larger premises at 13-17, Rathbone Street, London, W.1. The telephone number is Museum 5411.

Francis or Impulse Turbine?

Progress in constructing large Francis turbines in recent years has made it possible to employ this type also for high heads, that is, up to and even exceeding 500 metres. Consequently, when projecting a high-pressure power-station, the question arises as to whether the Francis or impulse type shall be given preference.

By CH. WEINGART, Escher Wyss Limited.

IT is not necessary to deal in detail with the actual calculations which have to be made in each individual case before this question can be answered, but these calculations will show whether the choice is restricted exclusively to either the Francis or the impulse type or whether the possibility exists of adopting either type for the prevailing conditions. In the direction of higher heads the use of a Francis turbine will be limited on the one hand either by the maximum permissible discharge velocity of the water issuing from the runner or by the highest possible speed in view of the strength of the generator rotor, and on the other hand by the minimum ratio of blade width to runner diameter, which can be adopted for reasons of efficiency. In the downward direction, namely towards lower heads, the suitability of an impulse turbine will be limited by the maximum number of jets that are possible—that is, either a horizontal arrangement with two runner wheels, each having two jets, or a vertical arrangement with one runner and four jets.

Resistance to Wear

Further reference will not be made to the danger of cavitation, because with Francis turbines it is practically always feasible to eliminate possible corrosion, arising from cavitation, by adopting the correct setting and by employing suitable materials; these precautions will at least keep the corrosion attack within the same limits as those for impulse turbines. The lower setting of the Francis will admittedly involve increased excavation work and more costly foundations, to which further reference will be made.

As regards the wear caused by erosion, it must first be mentioned that extreme cases, where the water is very sandy and which are cited by those in favour of impulse turbines, are not suitable for a comparison to be made between the two types, as the corrosive effects of such water cannot be withstood by either of them. In such instances there is no other course open than to clean the water as far as possible in a suitable sand-separating plant, no matter which type of turbine is used.

The parts of an impulse turbine which are chiefly subject to the action of the water are the nozzle insets, the needle points and the runner buckets. For Francis turbines, they are the upper and lower protecting rings of the guide apparatus, the guide vanes, the upper and lower stationary and rotating sealing rings and the runner blades.

In impulse turbines the nozzle and needles are subjected to the action of water issuing at a velocity that corresponds to the full head; in the Francis type, on the other hand, the water flows through the guide apparatus—especially under high loads—at a velocity which is, in part, considerably lower. Since wear increases with the velocity of the water, it follows that the nozzles and needles of an impulse turbine are subject to more rapid wear than the protecting rings of the guide apparatus and guide vanes of a Francis turbine.

Wear of the parts subjected to the action of the water affects the efficiency of an impulse turbine to a much greater extent than a Francis turbine. Even slight roughness of the nozzles and needles gives rise to considerable disturbance of the jet, which results in a corresponding reduction in efficiency, quite apart from the detrimental effects of eroded runner buckets.

Interesting information about the conditions in impulse turbines may be found in the paper by F. Aemmer* which refers to some investigations that were carried out on 30,000 h.p. impulse turbines operating under a head of 540 metres. The relatively quick wear of nozzles and needles (Fig. 1) is notable and it has been established that even minor wear has a very detrimental action on the operation of the turbines.

The relative velocity of the water in the runner blades or buckets is decisive in regard to wear and for reasons already explained is considerably higher in impulse turbines than in Francis turbines. A fur-

* "Bulletin des SEV," year 1943, No. 13 and "Schweiz. Bauzeitung," Book 126, Page 6 (7th July 1954), specially Fig. 8.

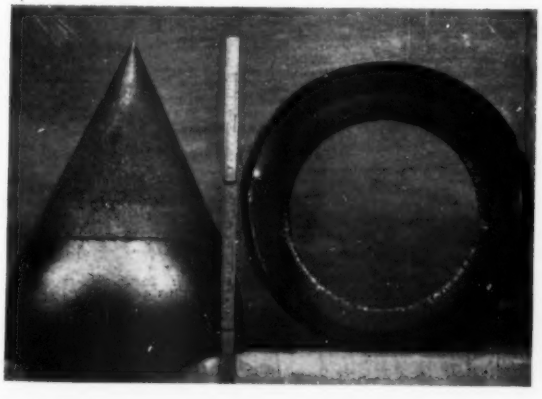


Fig. 1. Showing wear to needle heads and inset rings caused by sandy water

Fig. 2. Worn buckets on Pelton wheel, caused by sandy water

ther factor which favours the Francis turbine in this matter is that the wear is more uniform so that the profiles of the blades are deformed only to a slight extent. This is due to the uniform distribution of the water velocity over the surfaces.

In contradistinction to this the buckets of the impulse turbine exhibit a rippled form of attack, caused partly by disturbance of the jet arising from wear of the nozzles and needles and from the temporary distortion which ocurs when the deflector comes into action (Fig. 2).

As an interesting case in point reference may be made to a plant built by Escher Wyss in which three Francis turbines, each of approximately 25,000 h.p., operate under a head of 260 metres. As the construction of a sand-separating plant which had originally been projected had to be dispensed with for certain reasons, considerable wear of the turbines was caused by the exceptionally high content of sharp granite sand which occurred at certain times, thus making repairs necessary. The blade channels of the runner wheel proved to be the parts least affected and both the sides of the blades and the bottom of the channels showed the wear to be both regular and smooth. Only at the discharge points of the channels was the wear irregular, though not to a pronounced extent (Fig. 6).

As an example of the behaviour of a high-pressure Francis turbine operating under normal hydraulic conditions, one may mention the Bitto plant in Italy which works under a net head of 374 metres and has an output of 14,620 h.p. This unit has been in service almost without interruption since the beginning of 1944 and Figs. 7 and 8 show the excellent condition of the runner blades and rotating sealing rings after 33,000 hours' operation.

With Francis turbines it is the labyrinth rings which are most subject to wear. Impulse turbines have no such parts and this must be mentioned as an advantage. Sandy water passing at considerable velocity through the clearance spaces of a Francis turbine wears these labyrinth rings and gives rise to reduced efficiency as a result of the increased clearance losses. By adopting suitable dimensions for the labyrinth rings and using suitable materials for their manufacture, it has been possible to reduce this wear to a minimum, and also, to design the turbine in such a manner as to ensure speedy replacement of worn rings.

These endeavours to improve the design of Francis turbines to an even greater degree are still being continued. For example, reference may be made to the possibilty of making labyrinth rings of rubber or to introduce sealing water that is free from sand, the purpose being to render the entry of operating water more difficult.

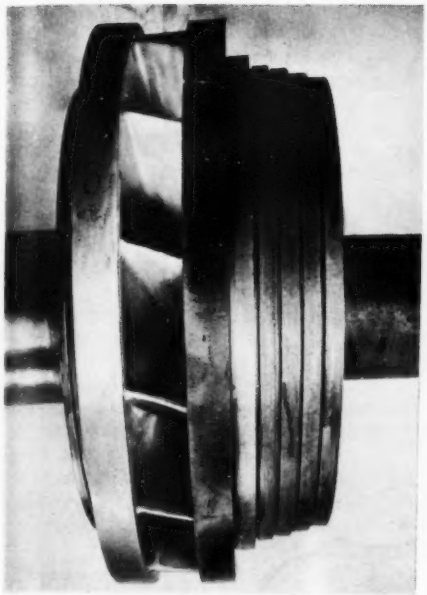
Unfortunately it is by no means easy to illustrate the behaviour of these two types of turbine with regard to wear, as reliable data on operating results are available to a very limited extent. Nevertheless, the few particulars that are available show that the wear of Francis turbines, particularly of the labyrinth rings, has proved to be less than has hitherto been assumed. As a characteristic example, reference may be made to a plant built by Escher Wyss where two 66,000 h.p. Francis turbines operating under a head of 346 metres have been in service for about nine years. The trials carried out on one of these sets after six years' service (15,000 working hours) resulted in the efficiencies shown in Table 1; it should be borne in mind that the specific speed of these turbines is very low.

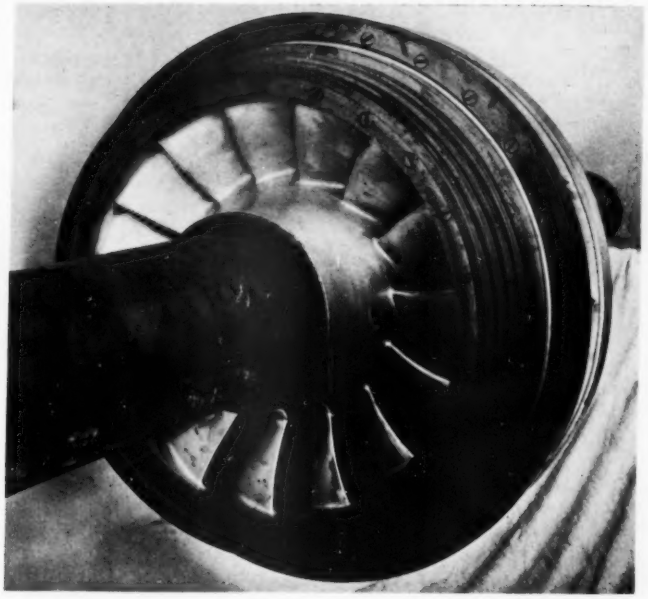
TABLE I. DEGREES OF EFFICIENCY OF HIGH-HEAD FRANCIS TURBINE WITH LOW SPECIFIC SPEED AFTER 33,000 WORKING HOURS

Load (h.p.)	68,250	64,190	58,310	49,720	41,420	34,050	27,630
Efficiency (%)	88·25	89·60	90·00	89·25	86·95	83·52	79·75

Unfortunately, efficiency tests were not carried out

Fig. 3. Worn runner of 25,000 h.p. Francis turbine, without external rim, caused by very sandy water under a head of 250 m. There is relatively little wear at the outlet points of the blade channels, otherwise the wear is slight and evenly distributed





Figs. 4 and 5. Runner of high-pressure Francis turbine installed at Bitto power station, Italy. This runner develops 14,620 h.p. under a head of 374 m. (1,180 ft.). After 33,000 hours' running the condition of the water passages and sealing ring will be seen to be excellent

when the plant was first put into service, so that it is not possible to know precisely to what extent the efficiency has fallen off in the intervening period. It can, however, be said that the measured efficiencies from full to one-half-load follow exactly the original guaranteed efficiency curve and lie about 0·5 per cent. below it in the maximum range.

Possibility of Repairing Worn Parts

In impulse turbines the nozzle and needles are designed in such a manner that they can easily be dismantled and replaced by spares, and any slight damage to the buckets can usually be repaired by grinding and welding, without the runner having to be removed. If, on the other hand, considerable

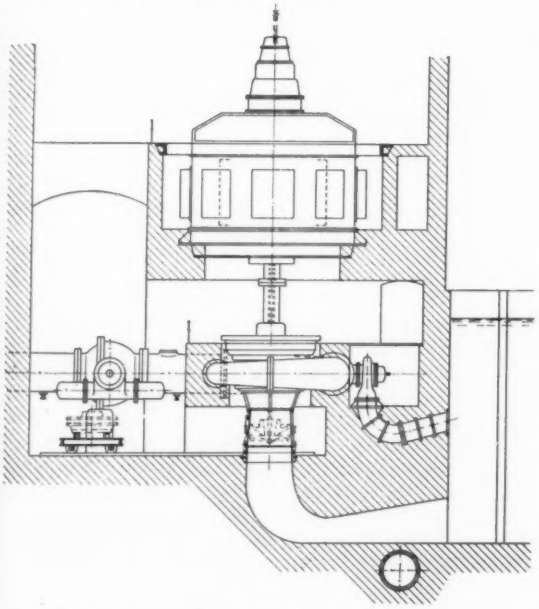


Fig. 6. Downward dismantling of high-pressure Francis turbine runner by lowering it into removable part of draft tube

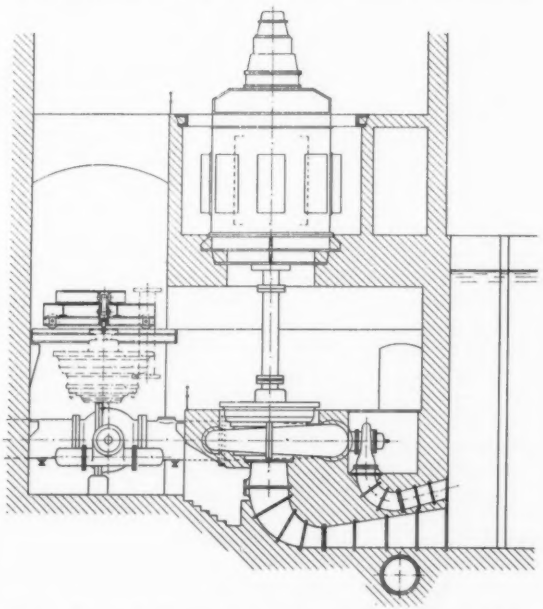


Fig. 7. Inward dismantling of runner wheel of a high-pressure Francis turbine after removing an intermediate shaft

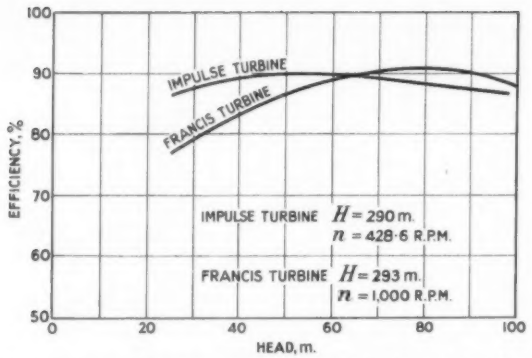


Fig. 8. The efficiency curve of a Francis turbine lies above that of an impulse turbine for the upper range of loads. The percentile difference may be small but it can give rise to an appreciable increase in the economy of a plant

damage occurs then there is no other course but to dismantle the runner and replace it by a spare wheel such as should always be available in an important installation. Repair of the damaged runner can then be carried out with the necessary care and without interrupting the operation of the plant. For vertical impulse turbines the runner can, depending on the design, either be taken out from above, removing the casing cover and guide bearing, or it can be dismantled from below with the aid of a special gear and placed on a truck especially provided for the purpose. The latter procedure has been found to be more convenient. Experience gained, for example, at the Innertkirchen and Handeck stations has proved that the replacement of runners, even where very large units are concerned, does not require more than 36 hours, so that it is possible to arrange for a runner to be replaced during a week-end when one set must in any case be shut down.

Such a relatively quick and easy replacement of a worn part was not at one time considered necessary for Francis turbines, when they were designed for medium heads and for operation with clean water. It was, of course, possible to remove any worn parts and to replace them by new or repaired parts, but this involved the necessity of shutting down the machine for a considerable time. Since Francis turbines began to be manufactured for high heads, however, impurities in the water have had to be taken into account and this has been done by so improving the design to ensure quick dismantling and easy replacement of the worn parts.

In installations less subject to disturbances in operation, and in which the wear is limited to the rotating sealing rings—usually of softer material—the runner wheel can be lowered on to a truck similar to that for impulse turbines and then transported to the repair shop (Fig. 6). With vertical-shaft units this is achieved in the majority of cases by removing the upper part of the draught tube, which is made in several sections for that purpose. Depending on circumstances, the sealing rings can be replaced by new ones, or a complete stand-by runner may be inserted.

If relatively speedy wear is anticipated, the Francis turbines should be so designed that, after removing a central shaft section between the turbine and generator shafts, the whole internal part of the turbine (comprising the runner and shaft section, the guide bearing, stuffing box, together with all the guide wheel vanes and the upper guide wheel cover) can be drawn out from above as a self-contained unit (Fig. 7) and replaced by a new or reconditioned unit. If everything is properly prepared beforehand, the time required to make this exchange should not exceed 50 to 60 hours, and is thus somewhat longer than that required for the average impulse turbine of similar power. On the other hand, for the reasons previously mentioned, the Francis runner has to be replaced on rarer occasions than the impulse wheel.

For a Francis turbine, the cost of a complete internal component will, in itself, be greater than that of an impulse unit of the same output in which only the runner, nozzle insets and needle heads are concerned. However, because of the smaller and lighter Francis runner as against the impulse-turbine runner, the difference in expenditure in relation to the total price of the equipment will not prove particularly important, especially in instances where the plant comprises a number of sets, for which spares for only one unit need be kept.

Plant Expenditure

An undisputed advantage of the Francis turbine lies in the fact that, for otherwise identical operating conditions, it can be built for a considerably higher speed than an impulse unit, and this leads to a smaller weight and lower price, not only of the turbine itself, but also of the generator. The higher speed may possibly involve a more complicated and expensive design for the generator, but experience has shown that with generators of European manufacture this is not necessarily the case. Although it must be admitted that the cost of the sets alone represents a relatively small percentage of the total cost of a plant, it must be pointed out that even a small increase in this total expenditure can affect the financial results of an undertaking to a considerable extent, in that the surplus between receipts and outlays can be effectively influenced by a relatively small increase in the quota reserved for amortisation.

In the matter of reduced plant expenditure, the smaller dimensions of high-speed sets enable the dimensions of the power house to be reduced, to which can be added the simpler inlet arrangement that is characteristic of Francis turbines as against multi-jet impulse turbines. Finally the travelling crane can be built for a lower lifting capacity and smaller span in view of the reduced dimensions of the power house.

On the other hand, to avoid cavitation, Francis turbines must usually have a lower setting than is necessary for impulse units. This usually leads to increased excavation work and correspondingly higher building costs where open installations are concerned. But where underground stations are considered, such an increase in the initial cost does not arise. It is not possible, of course, to give data that will be generally valid in regard to the reduced initial plant cost by adopting Francis turbines. This has to be determined in each case by detailed calculations, in which it must be investigated whether a smaller number of units of larger output—generally favourable to the high-pressure Francis turbine—affords a cheaper solution than the impulse type.

Economy of the Plant

The course of the efficiency curve has an important influence on the economy of the installation. From approximately 65 to 100 per cent. load the curve for the Francis turbines lies above that of a corresponding impulse turbine, whereas for loads below 65 per cent. its course is lower (Fig. 8). The general practice is to run turbines as far as possible within their upper range of loads; therefore, as a consequence of the better efficiency in the higher ranges, the energy production of a power plant equipped with Francis turbines will prove greater than that of a plant having impulse turbines when dealing with the same quantity of available water. In general this increase in energy production will not prove very great when expressed as a percentage. Nevertheless, it can give rise to an appreciable increase in the profit of an undertaking, for the same reason as was mentioned in regard to initial cost.

The loss in head caused by the so-called overhang of impulse turbines makes itself evident in a similar manner, although it is, as a rule, relatively small; nevertheless for the reasons already referred to it can have quite a pronounced negative influence on the financial results of an undertaking. This loss can become considerable when the overhang is necessarily large to accommodate pronounced fluctuations of water level in the tail-race channel. This loss of head does not occur with Francis turbines.

Finally the time during which the sets must be taken out of service for effecting repairs or replacing worn parts can in certain circumstances have an influence on the operating cost, and consequently on the economy of an installation. The question as to which type of turbine requires most time in this regard cannot, however, be answered in advance, as will be clear from previous remarks.

As regards governing there is no appreciable difference between the two types of turbine, provided that the Francis unit is equipped with a relief valve. A regulator of this kind reduces the maximum pressure increase which occurs when load is suddenly thrown off, normally to about 10 per cent. of the static pressure, so that danger to the pipeline is entirely avoided. By these means the momentary speed increase at part load can be kept within approximately the same limits as those for the impulse turbine. There is admittedly an appreciable difference in favour of impulse turbines as regards the speed increase when suddenly throwing off full-load, but this difference only plays a minor rôle in pracice, because the set is then entirely switched off from the network. Although the price of a Francis turbine is increased by the cost of the relief valve, this difference is less than the higher initial expenditure for the lower speed impulse turbine.

In Table 2 the main data relating to important high-pressure Francis installations, either supplied by Escher Wyss or on order, are given. If other smaller units are added the total capacity of these turbines exceeds $1\frac{1}{4}$ million horsepower. Some of these machines would previously have been designed as impulse turbines and many turbine makers would doubtless still recommend this type in similar conditions.

The hesitation of certain consulting engineers and manufacturing firms to recommend Francis turbines for high heads is not warranted and for heads up to 400 metres or even more, this type of turbine may be considered to be as equally good as the impulse type in regard to reliability of operation. If the many advantages of this type as compared with the impulse type are considered, the tendency to give preference to the Francis for the range of heads mentioned must be recognised as fully justified. Furthermore, it may be expected that future progress, involving the production of higher quality materials, will result in the Francis turbine being applied to even higher heads.

TABLE II. CHIEF DATA RELATING TO MODERN FRANCIS TURBINES WHICH HAVE ALREADY BEEN SUPPLIED BY ESCHER WYSS OR ARE NOW UNDER CONSTRUCTION

Installation	Country	Head in metres	Power single turbine	Total power h.p.	Revs. per min.
Rempen	Switzerland	260	22,500	90,000	500
Rjukanfos	Norway	280·5	17,500	17,500	600
Sauda	,,	230	30,000	90,000	500
Zappello	Italy	360	7,530	15,060	1260/1500
Rodund	Austria	346	66,200	264,800	500
Bitto	Italy	374	14,620	14,620	1260/1500
Mörel	Switzerland	260	24,900	74,700	750
Caterno	Italy	281	15,000	15,000	750
Devero	Italy	200	7,070	7,070	750
Saaheim	Norway	255	6,750	6,750	1000
Las Conchas	Spain	200	16,230	32,400	750
Julia	Switzerland	293	17,550	35,100	1000
Dobsina	Czechoslovakia	277	14,600	29,200	1000
Soverzene	Italy	284	74,500	74,500	360/428.7
Verbano	Switzerland	292	40,600	162,400	600
Escarra	Spain	316	8,000	8,000	1000
Fiastrone	Italy	333	20,140	40,280	1000

E.D.A. Industrial Film

The British Electrical Development Association have produced a film to emphasise the way in which electrical energy, combined with good planning, can be used for increasing industrial productivity. It is useless, the film suggests, to attempt to increase productivity simply by exhorting people to work harder, but rather, by proper planning, to place more horse power—electrical power—at his service. This inevitably necessitates an improved plant layout as a branch of industrial engineering. Various industrial techniques, such as mass, batch and unit production are shown on the work-flow principle, and interesting modern examples in the fields of materials processing and materials handling are illustrated.

Various types of industrial lighting have a prominent place in the film, and lighting as a tool is well demonstrated, including its significance in inspection where it facilitates quick and accurate work on a conveyor line. A number of special aids to production, including electrical vibrators and portable machine tools are also shown.

The film is entitled "Planned for the Purpose" and was produced by Greenpark Productions Limited, in association with the Film Producers Guild, the technical direction being by the Electrical Development Association. The film is available, on loan, in both 16 and 35 m.m. versions.

Heavy Eimco Tractor Loader

The Eimco Corporation have recently introduced a heavy model (105) tractor loader which is available with its own excavating attachment and other tools. The 105 is considerably stronger than the firm's previous large model and weighs approximately 34,000 lb., complete with loader. A number of improvements have been incorporated, the most important of these being a new Unidrive transmission which contains in one compact unit all the gearing and clutches for speed changing and independent reversal of each track. The design is said to combine all the best features of torque converter, constant-mesh gearing and hydraulically actuated friction clutches. Sealed oil bath and pressure lubrication of all wearing parts are other features. The oil-cooled, positive-engagement clutches are stated never to need adjustment. An important improvement made possible by the new transmission system is that it ensures the independent control of each track, and the ability to run one track forward and the other in reverse provide exceptional manoeuvrability for this machine.

The controls have been designed for simplicity, all movements of the tractor being controlled by two handles conveniently located immediately in front of the operator. An easy push on the two levers moves the machine forward and a pull reverses the machine, while twisting the levers provides a "spin" turn. By releasing either lever the machine is automatically able to return to neutral and to permit a "feathered" turn, or the track brake may be used to give a conventional turn.

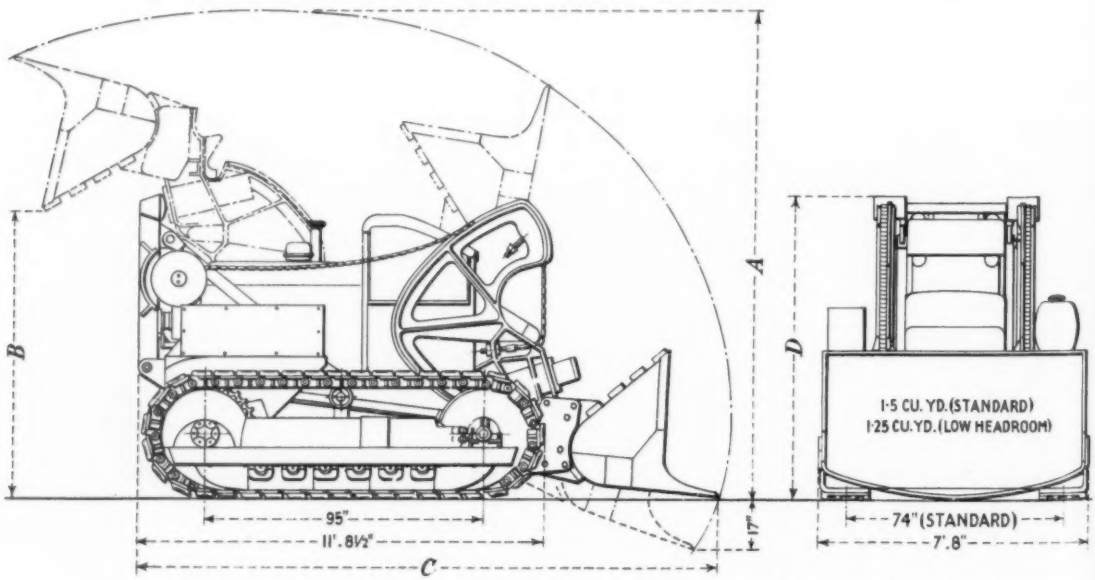
All parts, such as the transmission case, final drive cases and covers, are of heavy cast alloy or fabricated steel. Although the manufacturers believe that cast iron, customarily used for tractor parts, can be designed to give sufficient strength for average conditions, it is their opinion that an all-steel construction gives added strength for shock loading and the other stresses to which an excavator or tractor is subjected.

Two final drives are provided, one for each track. They have been designed in compact units and are separated by a spacer piece which forms the housing for the rear power take-off; this is one of the few pieces which needs to be changed when wider or narrower gauge tractor units are desired.

All gearing, sprockets, front idlers, and many other parts are of cast-alloy steel produced with liquid flame hardening. This method of tempering the outside rims, which are subject to strain, abrasion and fatigue, is claimed to retain the toughness necessary for long life in the internal portions of the piece hardened; moreover, it results in heat-treating distortion and scaling being eliminated. The track rollers are one-piece alloy-steel castings, machined and liquid flame hardened. Covers and guards are of cast steel and protect the lapped face seals which keep lubricant in and all moisture and foreign particles out.

The operator sits in front, thus obtaining excellent visibility when loading and bulldozing. The power units faces the rear and is located at the centre of the machine. A 90 h.p. diesel engine is provided, with matched torque converter, and it is claimed that this

Main overall dimensions	High-discharge model	Standard model	Low-discharge model
	ft. in.	ft. in.	ft. in.
A Headroom required	16 6	13 6	12 0
B Discharge height above ground (can be varied to suit requirements) ...	11 4	8 3	7 3
C Overall length—bucket down ...	17 6	16 6	15 1¼
D Overall height—bucket down ...	9 6	8 6	8 6



combination gives a most effective use of power.

The excavator, although differing from previous Eimco loaders, uses the same rocker-arm principle. The 105 loader is driven from the front power take-off of the engine and has a two-speed transmission of the same general type as the tractor, speed selection depending naturally on loading conditions.

The accompanying diagram indicates the general layout of the machine; the letters *A*, *B*, *C*, and *D* are explained in the table which gives detailed dimensions for the three models available—the high-discharge, standard and low-discharge models. Additional specifications may be briefly summarised as follows: the width of the track shoe is 16 in.; ground clearance, 12 in.; speed in low gear, forward and reverse, is up to 2 m.p.h., and in high gear, 5 m.p.h.

Ferranti Transformers

In the past twelve months the transformer department of Ferranti Limited has experienced great activity and the New Avenue factory at Hollinwood has turned out nearly 100 units of ratings between 10,000 and 75,000 kVA. Those shipped abroad include two 100,000 kVA 3-phase banks of 230 kV generator transformers for the Garrison Dam project, North Dakota, of the U.S. Corps of Engineers. One of the single-phase units is shown in our accompanying illustration and is rated at 33,000 kVA, 60 cycles, 13·2/230 kV. Other large transformers for overseas hydro-electric schemes include two 44,400 kVA, 3-phase banks of 220 kV generator transformers for the State Hydro-Electric Department, Roxburgh Power Station, New Zealand, while in Canada the erection was completed of the transformers for the Aluminium Company of Canada's project at Kitimat and Kemano. These transformers are now under load and an order has been received for a further bank of three 37 MVA 275 kV single-phase units for this project. Other orders received for large transformers connected with water-power schemes include three 56 MVA 115 kV single-phase units for the McNary Dam project U.S.A.

Zinc-Rich Protective Paints

Corrosion Limited, of Southampton, England, announce far-reaching improvements in their entire range of "cold galvanising" materials—otherwise zinc-rich paints containing particles of ultra fineness. According to the British Iron and Steel Research Association's definition, zinc-rich paints should contain between 92 and 95 per cent. of metallic zinc by weight in the dried film. In a booklet published by the Association in 1952 it was stated:

"Properly formulated zinc-rich paints have valuable protective properties. They are a reasonable substitute for galvanizing under some conditions of use, although they will generally be inferior to solid zinc coatings because of their lesser resistance to abrasion and the slow breakdown of the paint medium."

This finding, of course, relates to normal zinc-rich paints and Corrosion Limited claim that their latest product, "Glopane," makes a considerable step towards perfection. It is argued that the protection afforded by a zinc paint is dependent on the degree to which the metallic zinc is in contact with the steel or iron. Such is the fineness of the zinc particles in Glopane that it is claimed to have eight times the contact power of ordinary zinc-rich paints, so making the electrical system more perfect and greatly enhancing the protective properties of the coating.

Other advantages claimed for the new product are that the flow characteristics and hence the spreading properties are greatly improved, that it lends itself readily to the spraying technique, adhesion is excellent as zinc has an affinity for steel, that it gives a smooth finish and that it puts an end to sedimentation troubles as the pigment does not settle sufficiently to require a lot of tiresome "knocking up." Because of this last attribute the dipping of components is practicable.

Abstracts from the World Technical Press

Large-bore Tunnelling Machine

Using conventional methods of blasting and hand-mucking, tunnelling proceeds at a rate of one to two feet an hour. With the help of a novel machine of their own design, Mittry Constructors, a Los Angeles firm handling the $9.5 million tunnelling job at Oahe Dam, S.D., expect to make possible a rate of six to eight feet an hour. On the circular front of the machine are two large cutting heads formed like the spokes of two wheels; at the end of each spoke are sets of tapered disc cutters. The machine is mounted on rails and moved to a position opposite the section to be tunnelled out. Hydraulic jacks exerting a pressure up to 120 tons force the cutting head against the dirt and rock, and the cutting wheels are set into motion in opposite directions by two 200 h.p. motors. The earth is slashed with the knives on the two heads, and the ridges between the slashings broken down by the tapered disc cutters. This causes the debris to drop to the floor where it is scooped up by six buckets attached to the outer cutting wheel and then dropped on to a conveyor device which carries the muck to trucks. An overhead steel canopy and wooden siding cover the whole machine with the exception of the cutting heads, thus affording protection to workmen in the tunnel from falls of ground. Because the machine cannot travel backwards, it will have to be dismantled and brought out when the tunnelling operation is completed. The Oahe project, which requires eight miles of tunnels, is scheduled for completion in 1961. (*Electrical World*, December 13, 1954, p. 93, 2 ff.)

N.B.—A description of the above machine also appears in *Engineering News-Record*, Vol. 153, No. 23, 2.12.1954, p. 24/25, 3 ff.)

Oued El Abid Developments

These major Moroccan developments, carried into effect by *Energie Electrique du Maroc*, and scheduled for a yearly mean production of 550 million kWh, are expected to be in full operation in a very near future. They are divided into two groups: Bin el Ouidane at the confluence of the Oued Ahansal, and Ait Ouarda-Afourer, a few kilometres farther downstream. At Bin el Ouidane, a large storage reservoir with a gross capacity of 1,500 million cu. m. and an operating capacity of 1,160 million cu. m. is created by an arch dam 132·5 metres in height above the foundations and 173·7 metres in length at the crest; a ski-jump spillway is provided near the right bank. The power station, sited at the downstream foot of the dam, operates from a head varying between 60 and 105 m., and its three 40,000-kW generating sets can produce 160 million kWh per annum. The Ait Ouarda-Afourer installation comprises a single-arch dam 5 metres thick throughout, with a total storage of 2·5 million cu. m., from which a 4·5 metre dia. tunnel, 10,574 metres in length, leads to a surge chamber 30 metres in dia. at the bottom and 31 metres at the top. From the surge chamber, two penstocks feed each a 46,000-kW generating set operating from a gross head which varies between 235 and 228 metres. These two units will produce yearly 390 million kWh. Impounding at the Bin el Ouidane reservoir began early in 1953 and was completed in the Spring of 1954; the two generating groups were put into operation on October 19, 1953 and July 5, 1954 respectively, and production passed the 100-million kWh mark on October 1, 1954. The Ait Ouarda tunnel, driven from end to end and begun in March 1953, is now in course of completion, and the whole Ait Ouarda-Afourer group of the Oued el Abid developments is to be put into service very shortly. (*La Technique Moderne-Construction*, Vol. IX, No. 12, December 1954, p. 411, 8 pp., 7 ff.)

New Project of Zurich Corporation

Consumption in the area supplied by the Zurich Corporation has grown at such an annual rate (1,000 million kWh in the 1953/54 financial year against 670 million in 1947/48) that the increase substantially exceeds the output (216 million kWh) of the new Marmorea works which has been in operation since the autumn of 1953. The Corporation's Hydro-Electric Service, in search of new development possibilities, turned their attention to the Maira stream, and its tributary, the Albigna, in the Bergell district of the Grisons Canton, for which projects had been worked out as far back as 1904. Because of the difficult access to the Maira valley from Swiss territory, the remoteness of prospective plant sites from the consumption centres north of the Alps, and the unpredictable behaviour of the wild Bergell torrents, all these old projects were successively abandoned. The new project, called "Development Project 1954" (s. map appended), comprises two groups of works: the Albigna Works, with the Albigna storage lake, the intakes of Val Forno Orlegna torrent and Val Maroz (Upper Maira), together with their supply tunnels and the Löbbia power house; the Maira Works with the Castasegna power house, which utilises in a single stage the whole of the head between Löbbia and the Italian border. The gravity dam closing the Albigna lake (60 million cu. m. in capacity) will be no less than 755 m. in length at the crest, and will incorporate the old protective wall, 18 m. in height, built in 1929/30. In view of the impossibility of access by road to the dam construction site, transport is to be ensured by three cableways: (a) a permanent 3·5 ton shuttle-service cableway for passengers; (b) a slow 18-ton cableway for heavy material; (c) a 40-ton-per-hour roundabout cableway for cement. The Albigna-Löbbia supply works include a 4·6 km. pressure tunnel, a surge tank, a 1,100 m. long steel-lined pressure shaft connecting with the Löbbia penstocks 1600/1400 m. dia. and 750 m. long.The Orlegna supply tunnel will be 2·9 km in length. The generating equipment will be as follows:—at Albigna, two 35,000-kVA generators driven each by two 22,000 h.p. Pelton wheels, and a 10,000 h.p. Pelton wheel driving a 9,000-kVA generator-motor, with a storage pump having a maximum lift of 4 cu. m. per second; at Castasegna, the main units will be identical with those of Albigna, but there will be no pumping unit. Upon completion, the aggregate production of the Bergell installations will reach 237 million kWh or 54 per cent. in the October-March period, and 203 million kWh or 46 per cent. in the April-September period, i.e. a total of 440 million kWh per annum.

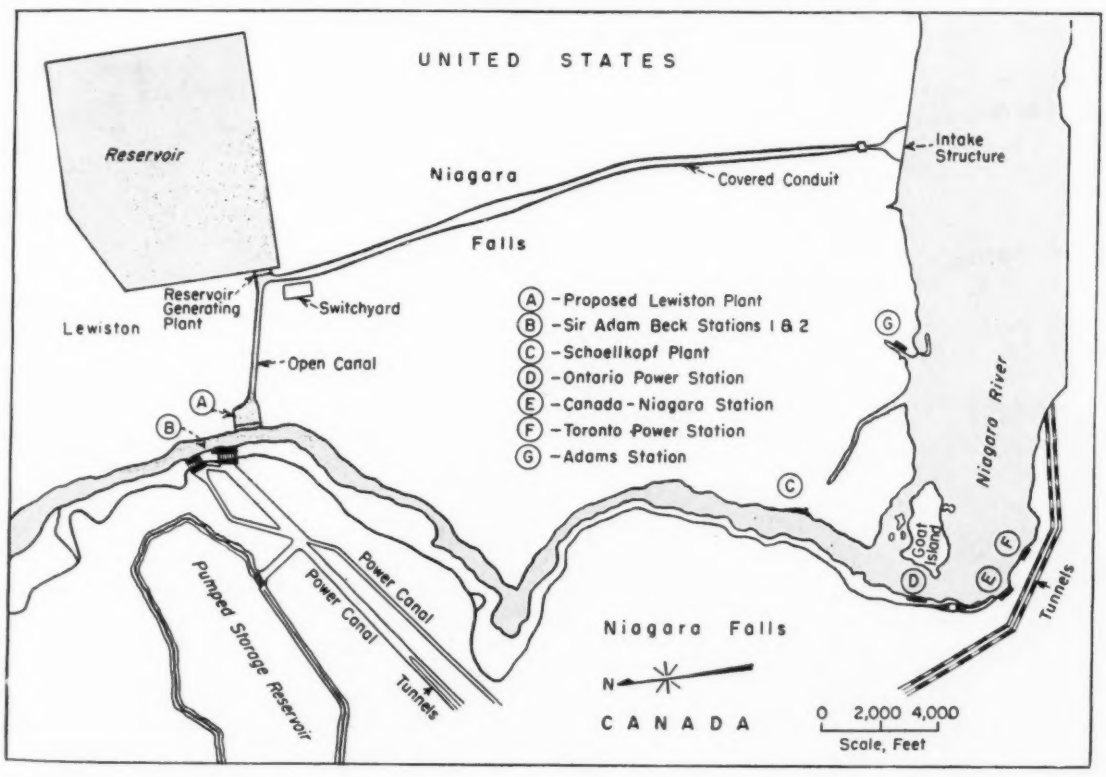
Construction work is to begin this year and generation is scheduled to start in the winter of 1959/60. The total cost of the project is estimated at 175 million Sw. Fr., with an additional outlay of 3 to 4 million Sw. Fr. for the 225-kV line connecting Löbbia with the outdoor switchyard of the Marmorea plant in Tingen, via Septimerpass and Bivio. (Head Engineer W. Zingg, *Wasser- und Energiewirtschaft*, Vol. 47, No. 1, January 1955, p. 1, 14 pp., 15 ff.)

Electric Industry in French Morocco

An account is given of the beginnings and expansion of electricity in French Morocco. Since the French established their Protectorate, the industrialisation of the country has advanced at such a rate that the utilisation of all the sources of energy available has become a major problem. Local coal and oil production is too limited to meet the growing needs in energy but, fortunately, French Morocco is the richest of all North-African countries in hydraulic resources and whereas up to 1928 electricity supply was the monopoly of thermal plants, a large part of Moroccan needs is now covered by hydro-electric production. The general concession for electricity supply is in the hands of a government-sponsored company, "Energie Electrique due Maroc," while distribution is divided among various concerns, of which the most important are "Société Chérifienne d'Energie" and "Régie des Exploitations Industrielles du Protectorat." Hydro-electric and thermal plants are equal in number, nine each; the installed capacity in 1953 was 144,200 and 105,400 kW respectively, i.e. a total of 249,600 kW, which was expected to reach the 300,000 mark by the end of 1954. The Oued el Abid development, now in progress, will substantially improve the position of hydro-electric production, and it is assessed that, at the beginning of next year, the aggregate installed capacity of hydro-plants in French Morocco will be 312,000 kW, and production 850 million kWh, out of a total of 415,000 kW and 1,200 million kWh. It is estimated that, at that stage, production will ensure a sufficient margin of security in relation to needs anticipated up to 1958. To meet future requirements beyond that time, investigations are now in progress with a view to utilising to the widest possible extent the hydraulic resources available in the basin of the Moulouya, the only river of French Morocco pouring into the Mediterranean, the Upper Sebou, flowing parallel to the border of the Spanish Protectorate, and the Oum ar Rabia, of which the Oued el Abid is a tributary. The main centres of consumption are Casablanca, Rabat and Mazagan on the N.W. coast, and Fez, Marrakesh and Oudza, three of the principal inland cities. The transmission lines, 4,251 km. in aggregate length, operate at either 150, 60 or 22 kV. Industry alone, mines and cement factories included, consumes no less than 56·5 per cent. of the energy produced, as against 26·47 per cent. for lighting and domestic purposes, and 10·97 per cent. for railways. (*Quaderni di Studi e Notizie*, Vol. 11, No. 188, 1.2.1955, 4 pp., 1 f., 3 tables.)

Development Plan for Niagara Falls

The New York State Power Authority has worked out plans for the American share of the new hydro-electric development at Niagara which envisage the erection (1) of a main power plant at Lewiston with



ten 150,000 kW generators; (2) pumping-generating plant operating in conjunction with an artificially constructed storage reservoir, and equipped with six generator-motor units rated at 20,000 kW as generators and using 28,000 kW as motors; (3) utilisation of covered conduit water passages between the intake and the forebay of the pumping plant, and of an open canal between the forebay of the pumping plant and the Lewiston Power Station. *(Electrical World,* Jan. 10, 1955, p. 53, 1 f.)

Hydro-electric Development in U.S.S.R.

The present stage of hydro-electric development in Russia is reviewed in broad outlines. At first sight, the resources of the country in water power appear enormous and, taking only 1,500 major streams into account, a yearly production of 2,450,000 million kWh seems to be within the realm of possibility. 1,300,000 million kWh being in Siberia where at least four rivers exceed the Volga in discharge. Two factors, however, restrict these possibilities: on the one hand, these giant streams flow at great distances from populated areas and, on the other, most of their developable stretches involve the setting up of low-head plants of very great size. In short, the hydraulic potential which could be economically harnessed to generation remains, for the present, comparatively limited while the need for electric energy has been unceasingly growing since 1920. In 1940, production was 48,000 million kWh for an installed capacity of 11·0 million kW; by the end of 1951, these figures had increased to 104,000 million kWh and 22·4 million kW, and production alone, which rose to 133,000 million kWh in 1953, was expected to exceed 145,000 million in 1954. The survey gives a short summary of the progress of work for each basin separately. At the present moment work is in progress on 40 hydro-electric developments, most of them multi-purpose schemes covering power generation, flood control, navigation, water supply and irrigation. As far as figures are given, it appears that Kuibyshev and Stalingrad plants are being built on an uncommonly large scale, both being designed for a production of 10,000 million kWh. Kuibyshev is to be equipped with 20 vertical kaplan sets of 103,000 kW each. The diameter of the alternators (17·5 m.) exceeds by 2·5 m. that of the Dnieprostroj units, and the rotors alone are 14·5 m. in dia. by 2·5 m. in height. To handle machinery components of such size, the power house will be equipped with two 450 ton travelling bridges. The 5,500 m. long sandfill dam, which creates a storage area of 5,000 million sq. m. and a head of 25 m., has a concrete spillway section 32 m. in height, fitted with 28 flood-control gates designed for a discharge of 70,000 cu. m. per sec. Once completed, the Kuibyshev works will have involved the placing of 6 million cu. m. of concrete, and 150 million cu. m. of earthwork. At Stalingrad, the installed capacity will be 1·7 million kW, the works following much the same pattern as at Kuibyshev. Compared with these large schemes the other plants described, Gorki and Molotov (Volga), Tsimliansk (Don), Novosibirsk (Ob), Boukhtarma (Irtytch), Lake Baikal (Angara, a tributary of the Yenissei), look rather small. Nevertheless, the dam crossing the Ob, 20 miles upstream of Novosibirsk, will extend to a length of 5 km., and the works which will divert yearly 20,000 million cu. m. of water from the Amu Daria to the Caspian Sea involve the digging of a canal 900 km. long and 150 m. wide at the water level, with a maximum draught of 4·5 m. And yet the whole of the Amu Daria works, including three power houses on the canal, will require only half the volume excavated at Kuibyshev. The Boukhtarma plant is, in Russia, one of the very rare examples of a dam with incorporated power house, set up in a deep gorge cut in granite; the dam proper, 100 m. in height will have a volume of 1·3 million cu. m., and the storage reservoir it creates will entirely submerge the great Zaissan Lake. The article, which includes a section on thermal plants, ends with a short paragraph on transmission lines; there are at present over fifty independent grid systems in U.S.S.R., each system covering areas up to 800 km. in diameter. (J. Talobre, *La Technique Moderne-Construction,* Vol. X, No. 1, January 1955, p. 12, 8 pp., 5 ff.)

New Project in Alberta

Preparatory work is in progress on the Battle River near Forestburg, Alberta, on a £2·5-million hydro-electric project for Canadian Utilities Ltd. The project is to include at its first stage an earthfill dam and a power house to be equipped at the outset with a 30,000-kW generating set. Construction work is to begin very shortly. *(Engineering News-Record,* Vol. 153, No. 23, Dec. 2, 1954, p. 42.)

New B.C. Project

Construction work on the new project of the British Columbia Electric Co. on the Cheakamus River, 70 miles north of Vancouver, is expected to begin towards the end of the year. It will provide an additional block of generating capacity of 142,000 kW. The main installations include an earth and rock dam 2,000 ft. in length at the crest and 90 ft. in maximum height. Penstocks at the downstream end of the 7-miles long tunnel will feed the turbines of the twin 71,000-kW generating units from a 900-ft. head. *(Engineering News-Record,* Vol. 153, No. 23, Dec. 2, 1954, p. 42.)

CLASSIFIED ADVERTISEMENTS

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IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY

ENGLISH ELECTRIC COMPANY'S BURSARIES IN HYDRO-POWER ENGINEERING

NOTICE IS HEREBY GIVEN that a number of English Electric Company Bursars in Hydro-Power Engineering will be elected in June, 1955. The Bursaries are of the value of £250 for one year tenable for postgraduate study in the Civil Engineering Department of the Imperial College. Bursars pay the appropriate College Tuition Fee. The Bursaries will be recommended for supplementation by the Ministry of Education.

Bursars who successfully complete the course will be eligible for the award of the Diploma of the Imperial College (DI.C.).

Candidates should have an Honours Degree in Engineering or an equivalent qualification, and applications should be received before 1st June, 1955, by the Deputy Registrar, City & Guilds College, Exhibition Road, London, S.W.7, from whom further details may be obtained.